

NASA CR-144813

IUE-581-75-078
CSC/TM-75/6137

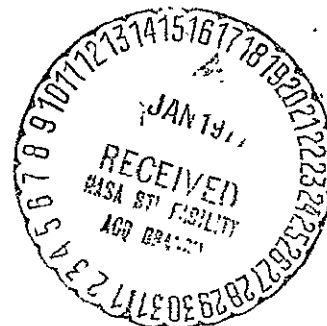
INTERNATIONAL ULTRAVIOLET EXPLORER (IUE) SATELLITE MISSION ANALYSIS

(NASA-CR-144813) INTERNATIONAL ULTRAVIOLET N77-15064
EXPLORER (IUE) SATELLITE MISSION ANALYSIS
(Computer Sciences Corp.) 92 p HC A05/MF
A01 CSCL 22A Unclas
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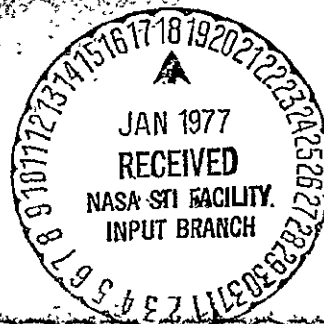
Prepared For
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Goddard Space Flight Center
Greenbelt, Maryland

CONTRACT NAS 5-11999
Task Assignment 544

SEPTEMBER 1975



CSC



COMPUTER SCIENCES CORPORATION

INTERNATIONAL ULTRAVIOLET EXPLORER (IUE) SATELLITE
MISSION ANALYSIS

Prepared for
GODDARD SPACE FLIGHT CENTER

By
COMPUTER SCIENCES CORPORATION

Under
Contract NAS 5-11999
Task Assignment 544

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ABSTRACT

This technical memorandum presents the results of the mission analysis performed by Computer Sciences Corporation (CSC) in support of the International Ultraviolet Explorer (IUE) satellite. The launch window is open for three separate periods (for a total time of 7 months) during the year extending from July 20, 1977, to July 20, 1978. The synchronous orbit shadow constraint limits the launch window to approximately 88 minutes per day. Apogee boost motor fuel was computed to be 455 pounds (206 kilograms) and on-station weight was 931 pounds (422 kilograms). The target orbit is elliptical synchronous, with eccentricity 0.272 and 24 hour period.

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SECTION 1 - INTRODUCTION

The objective of the joint United States/European International Ultraviolet Explorer (IUE) satellite is to observe the ultraviolet spectra of stars, galaxies, and the brighter gaseous nebulae. The IUE spacecraft will be launched by a 2914 Delta rocket and placed in a 24-hour elliptical orbit over the Atlantic Ocean. In support of this mission, Computer Sciences Corporation (CSC) has extended the mission analysis by performing the following tasks:

1. The launch window analysis was updated to reflect a nominal launch date of July 20, 1977. The FORTRAN Launch Analysis Program (FLAP) was used to determine the launch opportunities as a function of launch date and right ascension of the ascending node. The launch window is presented for a 1-year period beginning July 20, 1977.
2. The spacecraft weight was increased to accommodate higher payload requirements. The Two-Body Error Analysis (TBERR) Program was used to resize the apogee boost motor (ABM), assuming an apogee yaw maneuver in order to satisfy tracking requirements in the synchronous orbit. The resulting ABM fuel weight is 455 pounds (206 kilograms) which corresponds to a velocity change of 3540 feet per second (1078.9 meters per second). The hydrazine fuel requirements were computed for a nominal drift rate of 6 degrees per day east. The study assumed that drift rate errors would be corrected. The 99th percentile hydrazine required for station acquisition is 23 pounds (10 kilograms).
3. The shadow time history of the elliptical synchronous orbit was re-evaluated in light of recent changes in the constraints. To achieve maximum sunlight over a 5-year mission, a node and argument of perigee were selected to assure a high ecliptic inclination and apogee position well above the shadow cone of the Earth. The nominal node angle is 220 degrees and argument of perigee is 234 degrees.

4. The synchronous orbit inclination was chosen to satisfy tracking requirements at Goddard Space Flight Center (GSFC) and Villafranca del Castillo, Spain (VILFRA). The tracking time prediction program (SANDTRACKS) was used to determine tracking coverage as a function of inclination and station longitude.¹ If the nominal inclination is chosen to be 26.5 degrees, then the tracking constraints are satisfied. Furthermore, there is no significant loss of tracking time for points inside the .90 probability error ellipse centered at the nominal inclination.

5. The nominal trajectory parameters were computed for a July 20, 1977, launch. The transfer orbit node and argument of perigee were compensated for the apogee motor firing (AMF) maneuver. Second apogee was selected as nominal position for the AMF because of extensive tracking coverage from U.S. sites. The drift orbit was divided into three phases to achieve station acquisition in approximately 10 days. The nominal synchronous orbit has an eccentricity of 0.272, inclination of 26.5 degrees, and initial station longitude of about 42 degrees west.

Section 2 presents the launch window extending from July 20, 1977, to July 20, 1978. Section 3 updates the spacecraft weight breakdown, including a resized apogee boost motor and hydrazine fuel required for station acquisition. Section 4 outlines the nominal IUE mission profile, presents the trajectory constraints, and tabulates the nominal orbital elements designed to satisfy these constraints.

¹ Station longitude is defined as geographic longitude of the ascending node when the spacecraft is at the ascending node.

SECTION 2 - LAUNCH WINDOW ANALYSIS

2.1 LAUNCH WINDOW CONSTRAINTS

The launch window analysis for IUE was updated to extend from July 20, 1977, for a 1-year period.¹ The launch window constraints assumed for this study are as follows:

- Maximum continuous shadow duration prior to AMF must be less than 60 minutes
- Third-stage solar aspect angle must lie between 45 and 135 degrees
- Fourth-stage solar aspect angle must lie between 45 and 135 degrees
- Earth-spacecraft-Sun separation angle must be between 30 and 150 degrees for the 3-hour period prior to apogee
- Minimum daily launch window duration must be at least 20 minutes
- Synchronous orbit shadow duration must be less than 72 minutes per revolution for the entire mission

The pre-AMF shadow constraint must be satisfied from fairing ejection up to AMF. The solar aspect angle is measured between the spacecraft spin axis and the spacecraft-Sun vector (Figure 2-1). The separation angle is measured between the spacecraft-Sun vector and the spacecraft-Earth vector (Figure 2-2). The third stage injects the satellite into the transfer orbit from the parking orbit. The fourth stage is the ABM and is used to inject the satellite into the desired drift orbit.

¹ Computer Sciences Corporation, 3000-2700-07TN, Launch Window Analysis for the International Ultraviolet Explorer (IUE) Satellite, J. H. Griffin, March 1975

2.2 LAUNCH WINDOW DEFINITION

The launch window is defined in terms of launch date and node of the parking orbit. The composite launch window plot is presented in Figure 2-3, and the individual constraints are plotted in Appendix D.

The acceptable launch periods are approximately as follows:

- July 20, 1977 - August 24, 1977
- November 10, 1977 - February 14, 1978
- May 9, 1978 - July 20, 1978

These dates are determined primarily by the third- and fourth-stage solar aspect angle constraints, which rule out a total of about 5 months of the year. The acceptable node values are limited by the synchronous shadow history constraints, which are discussed in detail in Section 4. These limits slope downward in order to account for node regression in the synchronous orbit. For example, on the launch date of July 20, 1977, the shadow history can be computed with a given initial node value. To achieve the same shadow history for a launch date 5 months later, for example, the initial node must be compensated by an amount equal to a 5-month node regression.

It should be noted that the synchronous orbit node values will be about 6 degrees less than the parking orbit nodes, because of the plane change at AMF. This is true for any launch date. In Figure 2-3, this constant node shift has been accounted for in plotting the node limits associated with the synchronous orbit shadow history constraints.

Also in Figure 2-3, note that there are no violations of the Earth-Sun separation angle constraint for the node range under consideration. This is due to the relatively high inclination of the orbit with respect to the ecliptic plane.

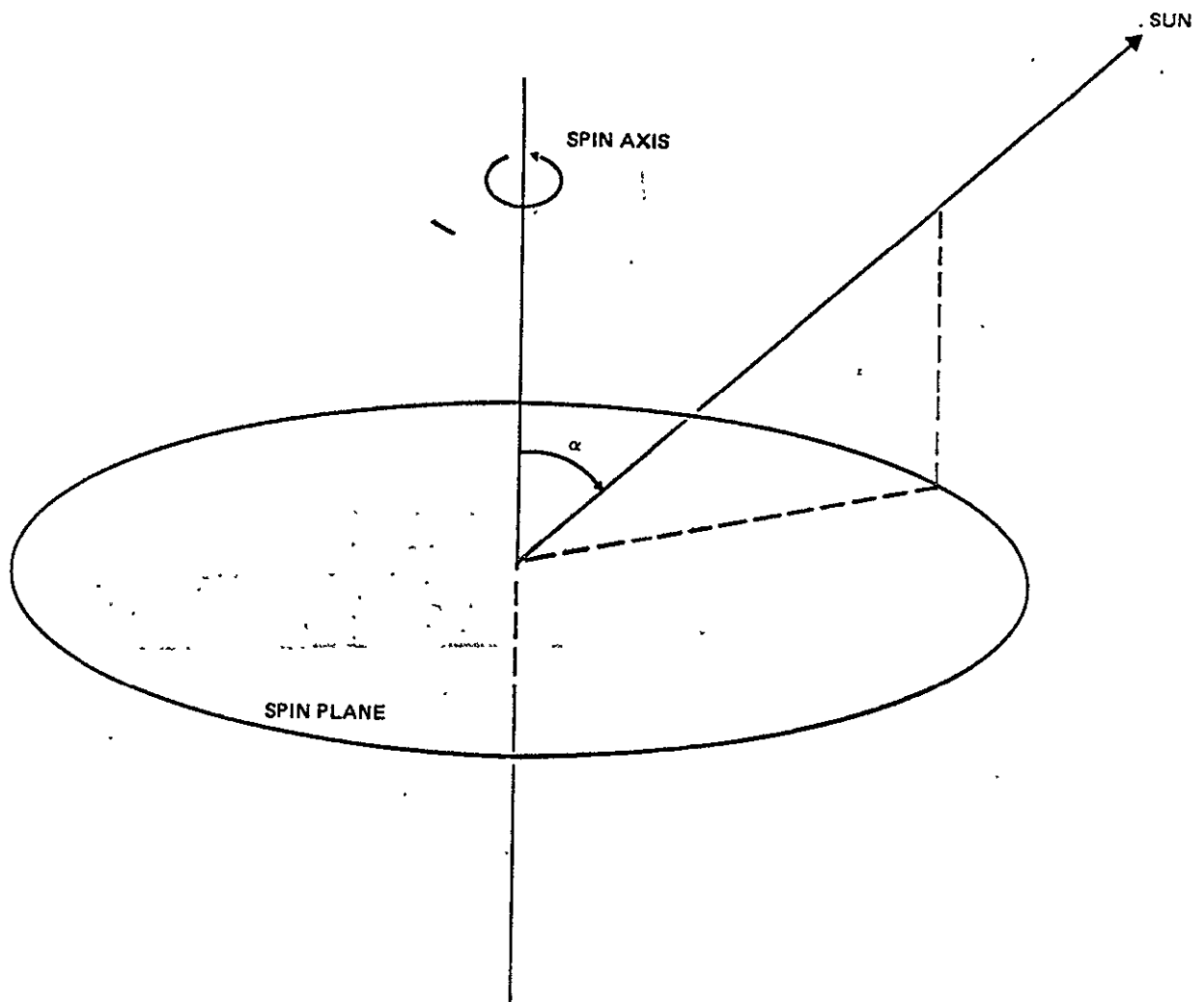


Figure 2-1. Definition of Solar Aspect Angle (α)

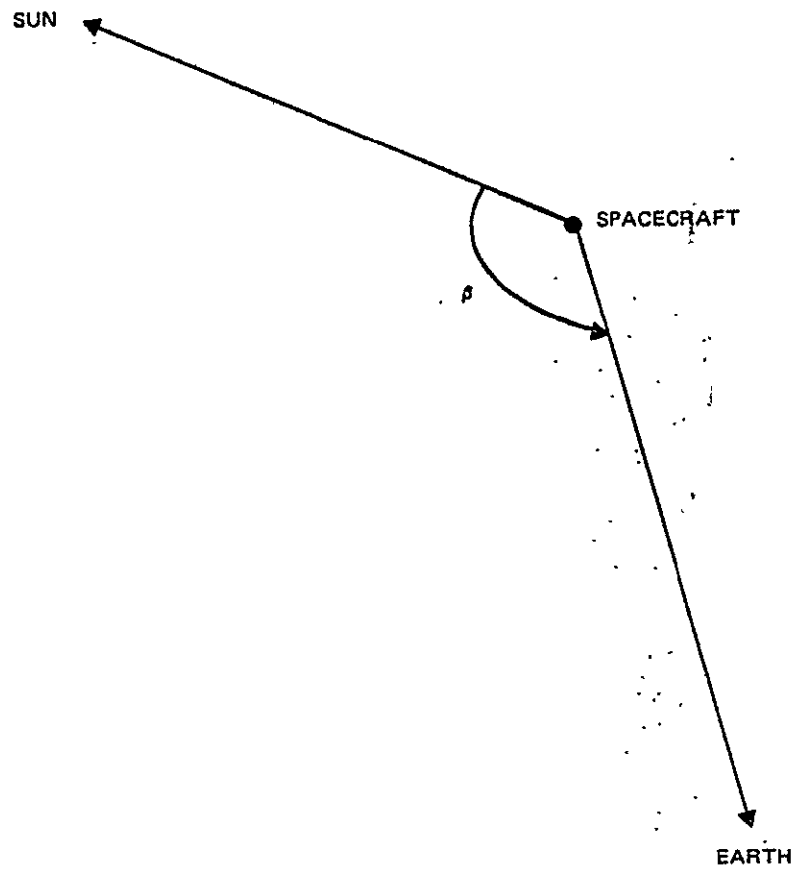


Figure 2-2. Definition of Separation Angle (β)

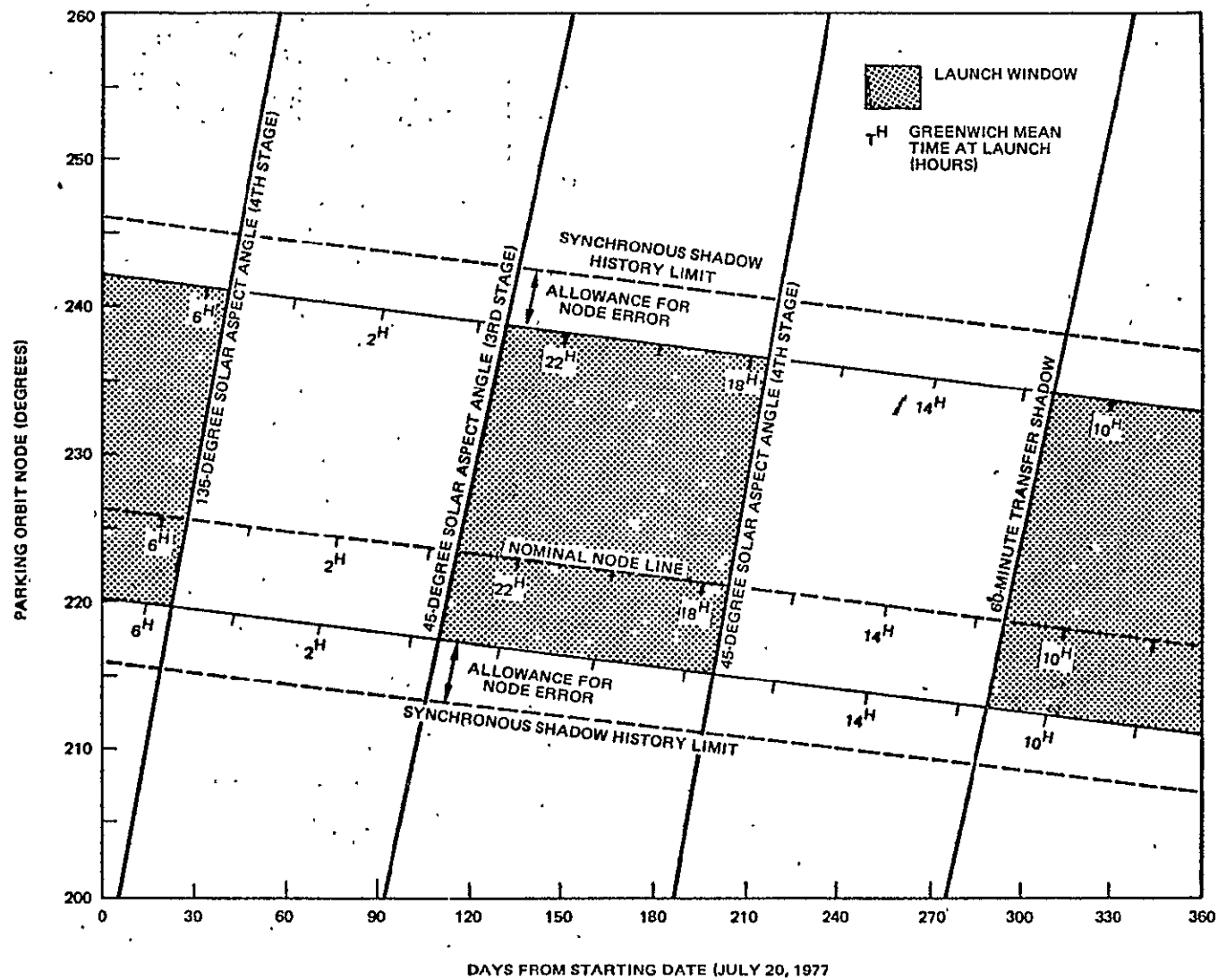


Figure 2-3. IUE Launch Window

SECTION 3 - FUEL REQUIREMENTS

3.1 APOGEE BOOST MOTOR SIZING

Using the TBERR Program, the ABM was resized to account for increased spacecraft weight. The transfer orbit inclination was 28.7 degrees (defined by launch azimuth) and the apogee bias was 5700¹ nautical miles (10556 kilometers). The target inclination was varied from 24.0 to 28.7 degrees, and the ABM fuel was computed assuming a nominal target drift rate of 6 degrees per day east. The ABM fuel penalty versus inclination is shown in Figure 3-1, where zero penalty represents no plane change between the transfer and synchronous orbits. The selection of the nominal inclination (26.5 degrees) is discussed in Section 4.2. For an inclination of 26.5 degrees, the impulsive velocity change (ΔV) is 3540 feet per second (1078.9 meters per second). The corresponding ABM fuel required is 455 pounds (206 kilograms), assuming an effective specific impulse of 280.6 seconds.

3.2 HYDRAZINE AND ON-STATION WEIGHT

To determine the station acquisition hydrazine required, a Monte Carlo simulation was performed using the TBERR Program. The covariance matrix for position and velocity at transfer orbit injection is presented in Table 3-1. Additional errors are introduced during the AMF. The ABM 3-sigma pointing error was assumed to be 5 degrees in both yaw and pitch. The 3-sigma error in ABM ΔV was assumed to be 0.75 percent.

Two hydrazine maneuvers were simulated in the drift orbit. If the sample drift rate deviated by more than 0.1 degree per day from the nominal value of 6 degrees per day, a hydrazine burn was performed to correct the drift rate back to the nominal value. A second hydrazine burn reduces the drift rate to zero to achieve a synchronous orbit. (The purpose of the drift orbit is to allow

¹This bias is a project requirement, imposed to limit eccentricity in the synchronous orbit.

the spacecraft to acquire a specified station longitude.) If the sample eccentricity was greater than nominal, two hydrazine burns were performed to achieve the synchronous orbit. The eccentricity was lowered to the nominal value, while the drift rate was reduced to zero. In either case, the 99th percentile¹ hydrazine fuel is 23 pounds (10 kilograms), assuming a specific impulse of 220 seconds. This does not include any fuel required for spin rate control or attitude trim maneuvers. Table 3-2 presents an approximate IUE weight breakdown. The pre-AMF and post-AMF reorientation hydrazine values are estimated to be 4 and 2 pounds, respectively. Histograms for pertinent parameters are presented in Appendix A.

¹For hydrazine used to acquire station, N percent of the sample values are less than the Nth percentile value.

Table 3-1. Covariance Matrix at Transfer Injection

	x	y	z	\dot{x}	\dot{y}	\dot{z}
x	116322450.0	-1528932.4	-30565341.0	59126.868	83.506098	-142975.58
y	-1528932.4	63602375.0	706100.71	-1191.2372	5900.6438	1863.5505
z	-30565341.0	706109.71	25449260.0	-22264.382	16.078010	64165.883
\dot{x}	59126.868	-1191.2372	-22264.382	255.0	117.07503	-200.2417
\dot{y}	83.506098	5900.6438	16.078010	117.07503	8836.1771	-0.11295046
\dot{z}	-142075.58	1863.5595	64165.883	-200.2417	-0.11295046	9050.9395

1. POSITION IN FEET; VELOCITY IN FEET/SECOND.

2. COORDINATE SYSTEM.

$$\underline{Z} = \underline{R}$$

$$\underline{Y} = \underline{R} \times \underline{V}$$

$$\underline{X} = (\underline{R} \times \underline{V}) \times \underline{R}$$

WHERE \underline{R} AND \underline{V} ARE THE INERTIAL POSITION AND VELOCITY VECTORS.

Table 3-2. Approximate Weight Breakdown for IUE.

ITEM	ENGLISH UNITS	METRIC UNITS
WEIGHT AT THIRD STAGE BURN-OUT	1415 LBS	642 KG
PRE-AMF REORIENTATION HYDRAZINE (ESTIMATE)	-4	-2
WEIGHT AT AMF	1411	640
ABM PROPELLANT AND INERT CONSUMMABLES	-455	-206
POST-AMF WEIGHT	956	434
POST-AMF REORIENTATION HYDRAZINE (ESTIMATE)	-2	-1
STATION ACQUISITION HYDRAZINE (99TH PERCENTILE)	-23	-10
ON-STATION WEIGHT (99TH PERCENTILE)	931	422

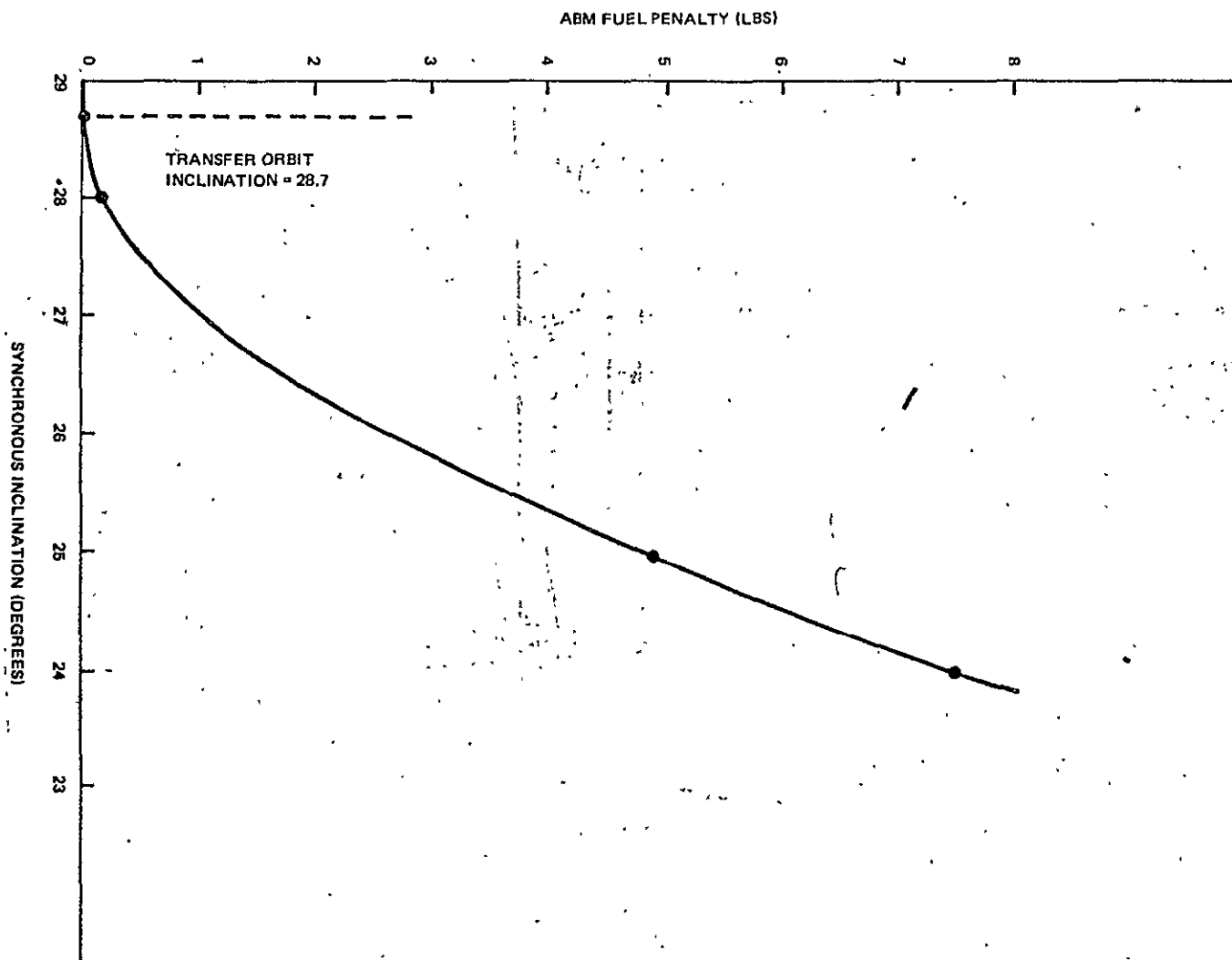


Figure 3-1. ABM Fuel Penalty Versus Inclination (for Fixed Apogee Bias and Fixed Drift Rate)

SECTION 4 - NOMINAL TRAJECTORY

4.1 SHADOW TIME CONSTRAINT

The nominal node and argument of perigee of the elliptical synchronous orbit were chosen to satisfy the shadow time constraint. Synchronous shadow duration must be less than 72 minutes per revolution over a 5-year mission. Due to the orbital eccentricity, the actual shadow durations could be as high as 95 minutes. To avoid these situations, the orientation geometry of the orbit plane must be controlled. The shadow constraint is satisfied when the orbit plane achieves a relatively high ecliptic inclination (Figure 4-1) and when the apogee position is well above the shadow cone of the Earth (Figure 4-2; ecliptic argument of perigee near 270 degrees). These conditions are met using an initial node of 220 degrees and argument of perigee of 234 degrees.

Figure 4-3 shows the 5-year synchronous orbit shadow history for the nominal elements. In generating this curve, semimajor axis, eccentricity, and inclination were held fixed, while node and argument of perigee were allowed to evolve at constant rates¹ of -0.024 and $+0.027$ degree per day, respectively. Figure 4-4 through 4-7 show the shadow histories for the 99th percentile values of argument of perigee for various node angles. For node angles from -10 to $+20$ degrees about the nominal value, the umbra shadow curves are acceptable and provide launch window durations of about 88 minutes per day (after compensating for possible node errors), as shown in Figure 2-3. For higher or lower node angles, the shadow curves are marginal or unacceptable, as shown in Appendix B.

4.2 TRACKING REQUIREMENTS

The synchronous orbit inclination was chosen to satisfy tracking requirements at GSFC and VILFRA. GSFC tracking time must be 24 hours per day, and

¹This is due to the oblateness of the Earth, as reflected in the J2 coefficient in the gravitational potential.

VILFRA tracking time must be at least 10 hours per day. Figure 4-8 shows the GSFC tracking mask (NTTF 12-meter antenna) and a portion of the nominal tracking pattern. Figure 4-9 shows the VILFRA tracking mask and the nominal tracking pattern. The physical mask plus 10 degrees was used in computing all tracking time for VILFRA.

SANDTRACKS was used to compute tracking time as a function of inclination, argument of perigee, and longitude at the ascending node.¹ A representative sample of this data is presented in Table 4-1. The western-most limit of longitude at the ascending node is determined by the VILFRA tracking constraint, and the eastern-most limit is determined by the GSFC tracking constraint. Some of the longitude intervals, where both tracking requirements are satisfied, are indicated in Figure 4-10.

This figure also shows the .90 probability error ellipse for argument of perigee and inclination. The ellipse is centered at the nominal inclination of 26.5 degrees. Even though the ellipse extends into the region of tracking constraint violation, the loss of tracking time was not considered significant. For points A, B, and D on the ellipse, the VILFRA tracking time is about 9.4 hours when GSFC has 24 hours of coverage. At point C, the VILFRA coverage is 8.8 hours. As the orbit evolves, the inclination tends to decrease and the argument of perigee increases, resulting in better tracking coverage. If point C represents the initial conditions for the synchronous orbit, then after approximately 5 months the tracking requirements would be completely satisfied.

For nominal initial conditions, the orbit was allowed to evolve over a 5-year mission, and the longitude limits were determined as shown in Figure 4-11. To keep the orbit within these limits, it is necessary to perform stationkeeping maneuvers throughout the mission.

¹This longitude is the geographic longitude of the ascending node when the spacecraft is at the ascending node.

4.3 NOMINAL MISSION PROFILE

The current nominal launch date for IUE is July 20, 1977. On this date, the launch window is open from approximately 6.9 to 8.4 hours GMT. This corresponds to a transfer node range of 220 to 242 degrees, or a synchronous node of 214 to 236 degrees.

IUE will be launched by a three-stage Delta 2914 vehicle from Cape Kennedy at a launch azimuth of 95 degrees. At an altitude of 100 nautical miles, it will be injected into a circular parking orbit with an inclination of 28.7 degrees. After coasting for about 26 minutes, the booster injects the spacecraft into a transfer orbit with an argument of perigee of 228.7 degrees. Following injection into the transfer orbit, the spacecraft orbit and attitude will be computed from tracking and telemetry data. The hydrazine reaction control system will then reorient the spacecraft into the apogee motor firing attitude. On the second apogee passage of the transfer orbit, the ABM will inject the satellite into a near-synchronous drifting orbit. The ABM will perform a plane change maneuver resulting in an inclination of 26.5 degrees, node of 220 degrees, and argument of perigee of 234 degrees. Drift rate will be controlled by the hydrazine system until the satellite acquires station. The final orbit will be elliptical synchronous.

4.4 NOMINAL ORBITAL ELEMENTS

The parking orbit is defined by the following parameters:

<u>Parameter</u>	<u>Description</u>
Altitude	100 nautical miles (185 kilometers)
Eccentricity	0
Inclination	28.7 degrees
Injection latitude	24.77 degrees
Injection longitude	59.49 degrees west
Injection azimuth	105.28 degrees

<u>Parameter</u>	<u>Description</u>
Time from launch to injection	539.37 seconds
Coast time	1599.35 seconds
Epoch date	July 20, 1977
Epoch time	7 ^H 13 ^M 42 ^S

The transfer, drift, and synchronous orbits are defined in Table 4-2. At AMF, the spin axis right ascension is 5.27 degrees, and the declination is 11.26 degrees, for the nominal orbit. Errors in the orbital elements are listed in Table 4-3 and shown in histogram form in Appendix A. Figures 4-12 through 4-17 display the spacecraft groundtracks, while Appendix C presents the corresponding tracking coverage.

4.5 NOMINAL STATION ACQUISITION SEQUENCE

As presented in Table 4-2, the drift orbit is divided into three phases with drift rates of 6 and 2 degrees per day east. This represents only one of many possible station acquisition sequences to achieve a synchronous orbit. Table 4-4 indicates time to acquire station for easterly and westerly drift rates of 6 degrees per day, assuming AMF occurs on one of the first five transfer apogee passes (second apogee is nominal). Initial station longitude is near 42 degrees west. Figure 4-18 presents the station acquisition sequence in terms of longitude at the ascending node as a function of the number of revolutions in the drift orbit. After station longitude has been achieved, the higher order gravitational effects cause the orbit to deviate significantly away from the initial conditions. Figure 4-19 shows the evolution of the longitude at the ascending node if there are no stationkeeping maneuvers. Appendix E presents the evolution of the orbital elements and the groundtrack evolution.

Table 4-1. Longitude Intervals for Good Tracking

ARGUMENT OF PERIGEE (DEGREES)	VILFRA MINUS GSFC STATIONKEEPING LONGITUDES (DEGREES WEST)		
	INCLINATION = 25 DEG	INCLINATION = 26 DEG	INCLINATION = 26.5 DEG
226	$44 - 36 = 8$	$44 - 38 = 6$	$44 - 38 = 6$
230	$44 - 34 = 10$	$44 - 36 = 8$	$44 - 36 = 8$
234	$44 - 32 = 12$	$44 - 34 = 10$	$44 - 40 = 4$

Table 4-2. IUE Nominal Orbits

PARAMETER	TRANSFER ORBIT	DRIFT PHASE 1	DRIFT PHASE 2	DRIFT PHASE 3	SYNCHRONOUS ORBIT
SEMIMAJOR AXIS (KM)	29642	41703	42010	42119	42164
ECCENTRICITY	0.77858	0.26417	0.26955	0.27144	0.27221
INCLINATION (DEG)	28.7	26.5	26.5	26.5	26.5
ASCENDING NODE (DEG)	225.9	220	220	220	220
ARGUMENT OF PERIGEE (DEG)	228.7	234	234	234	234
MEAN ANOMALY (DEG)	0.0	180	0.0	0.0	0.0
EPOCH DATE	7/20/77	7/21/77	7/24/77	7/27/77	7/29/77
EPOCH TIME	7H49M21S	4H53M21S	15H17M27S	14H41M53S	14H29M30S
DRIFT RATE (DEG/DAY EAST)		6.0	2.0	0.577	0.0
PERIOD (HR)	14.110	23.543	23.803	23.896	23.934
PERIGEE RADIUS (KM)	6563	30686	30686	30686	30686
APOGEE RADIUS (KM)	52720	52720	53334	53552	53642

INITIAL STATION $\approx 42^\circ$ W

Table 4-3: 99th Percentile Errors in Orbital Parameters

PARAMETER	TRANSFER ORBIT ERRORS		DRIFT ORBIT ERRORS		SYNCHRONOUS ORBIT ERRORS	
ECCENTRICITY	-0.003	+0.004	-0.004	+0.007	-0.014	+0.0
INCLINATION (DEG)	-0.2	+0.2	-1.0	+1.1	-1.0	+1.1
NODE (DEG)	-0.6	+0.6	-3.4	+3.1	-3.4	+3.1
ARGUMENT OF PERIGEE (DEG)	-1.0	+1.1	-5.6	+5.6	-5.6	+5.6
RADIUS OF PERIGEE (KM)	-3.6	+3.3	-696	+504	0.0	+590
RADIUS OF APOGEE (KM)	-972	+1004	-993	+1017	-590	0.0
DRIFT RATE (DEG/DAY)			-11.0	+9.9	0.0	0.0

Table 4-4. Time To Acquire Station for Easterly and Westerly Drift Rates

TRANSFER APOGEE PASS	DEGREES TO STATION		DAYS TO STATION	
	EAST	WEST	DRIFT 6 DEG/DAY	DRIFT 6 DEG/DAY
1	176	184	29	31
2	27	333	5	55
3	238	122	40	20
4	90	270	15	45
5	301	59	50	10

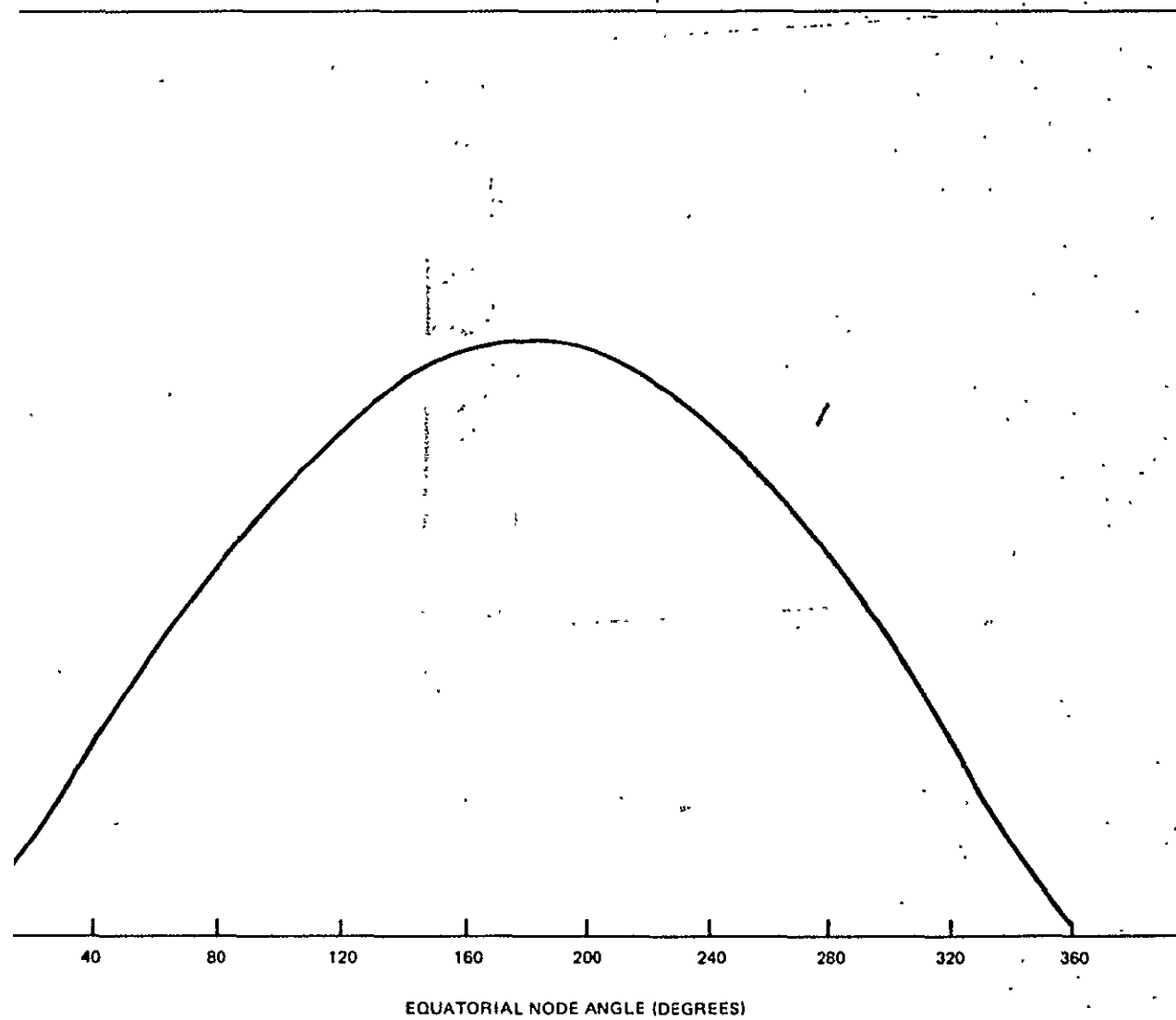


Figure 4-1. Ecliptic Inclination

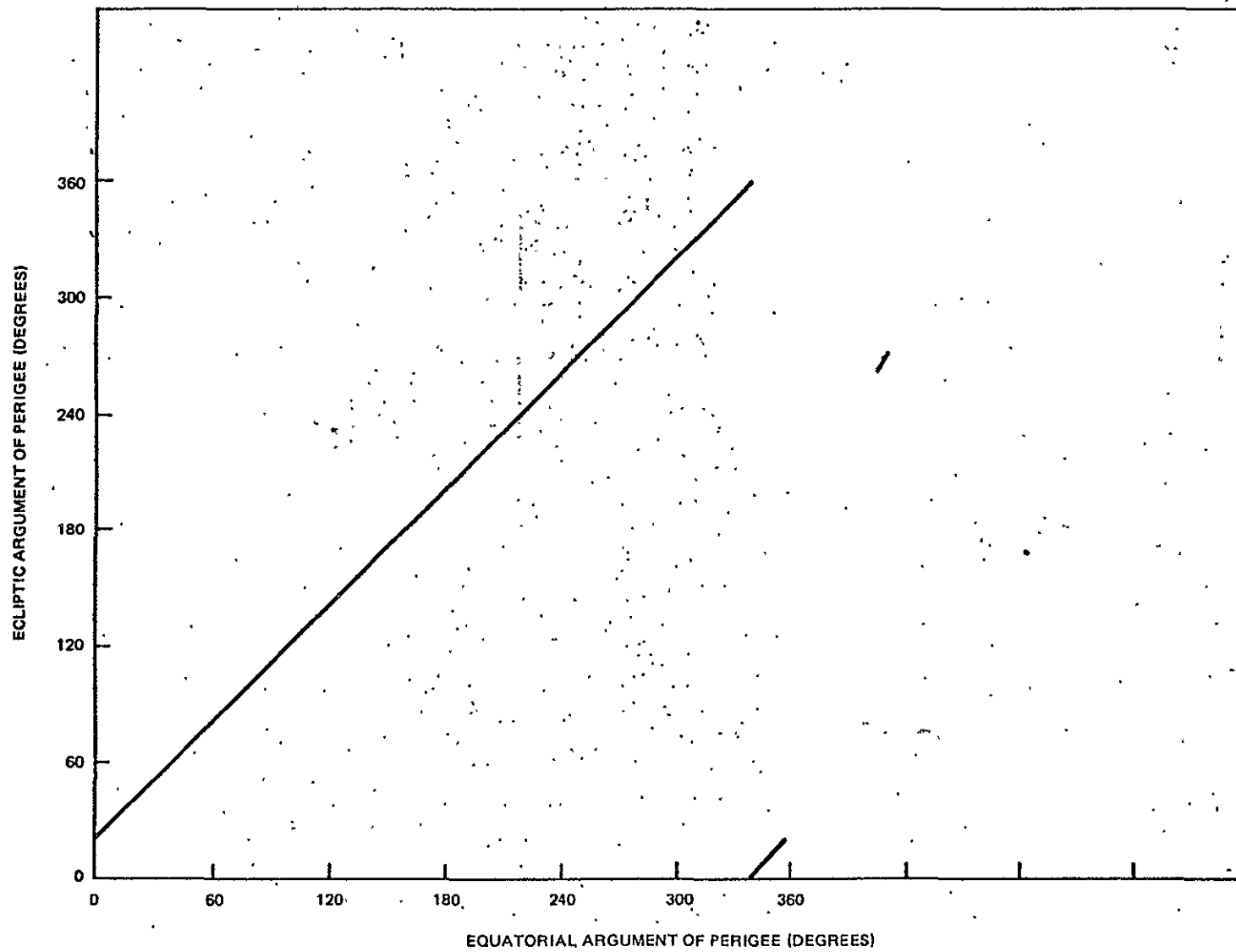


Figure 4-2. Ecliptic Argument of Perigee

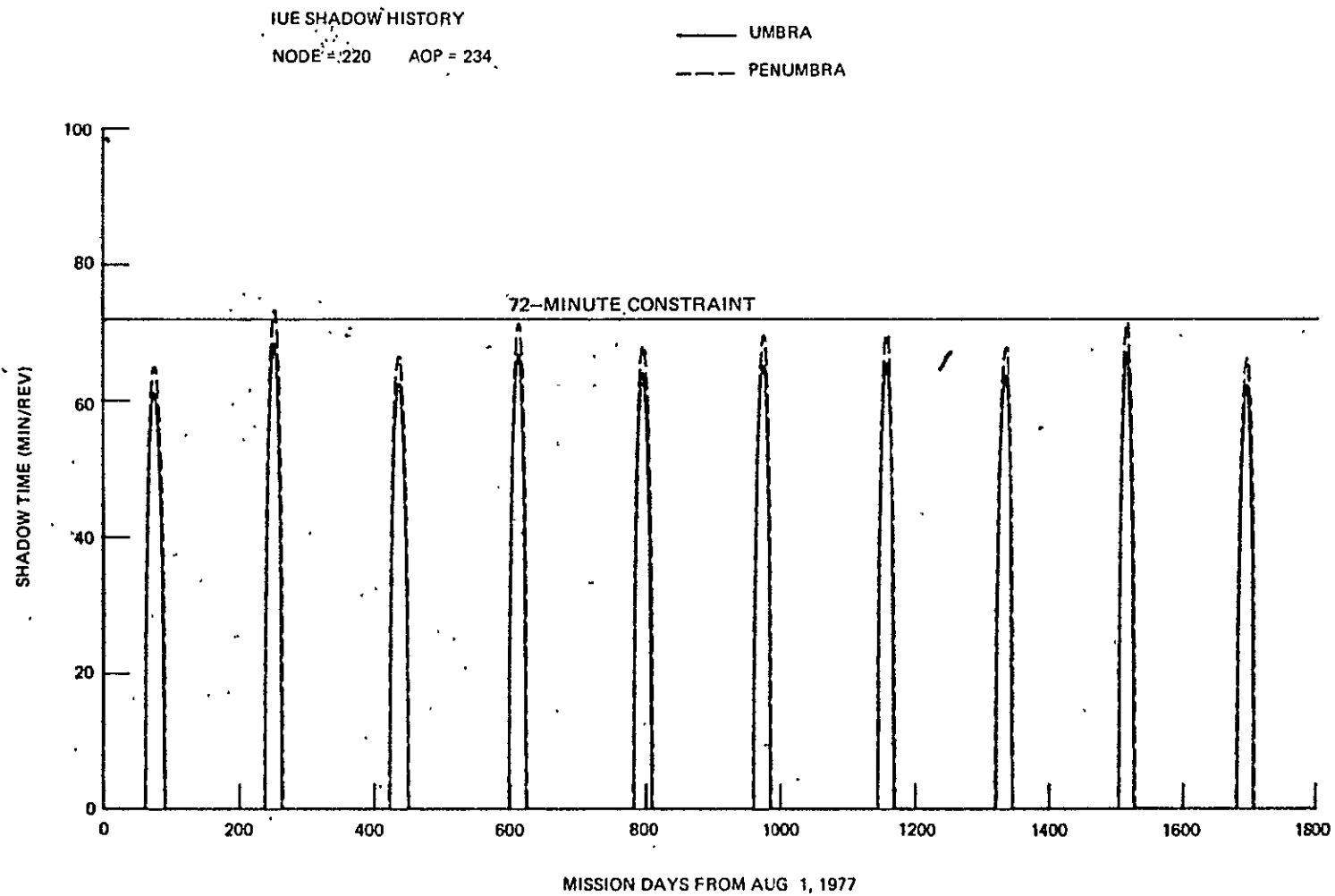


Figure 4-3. Nominal Synchronous Orbit Shadow History

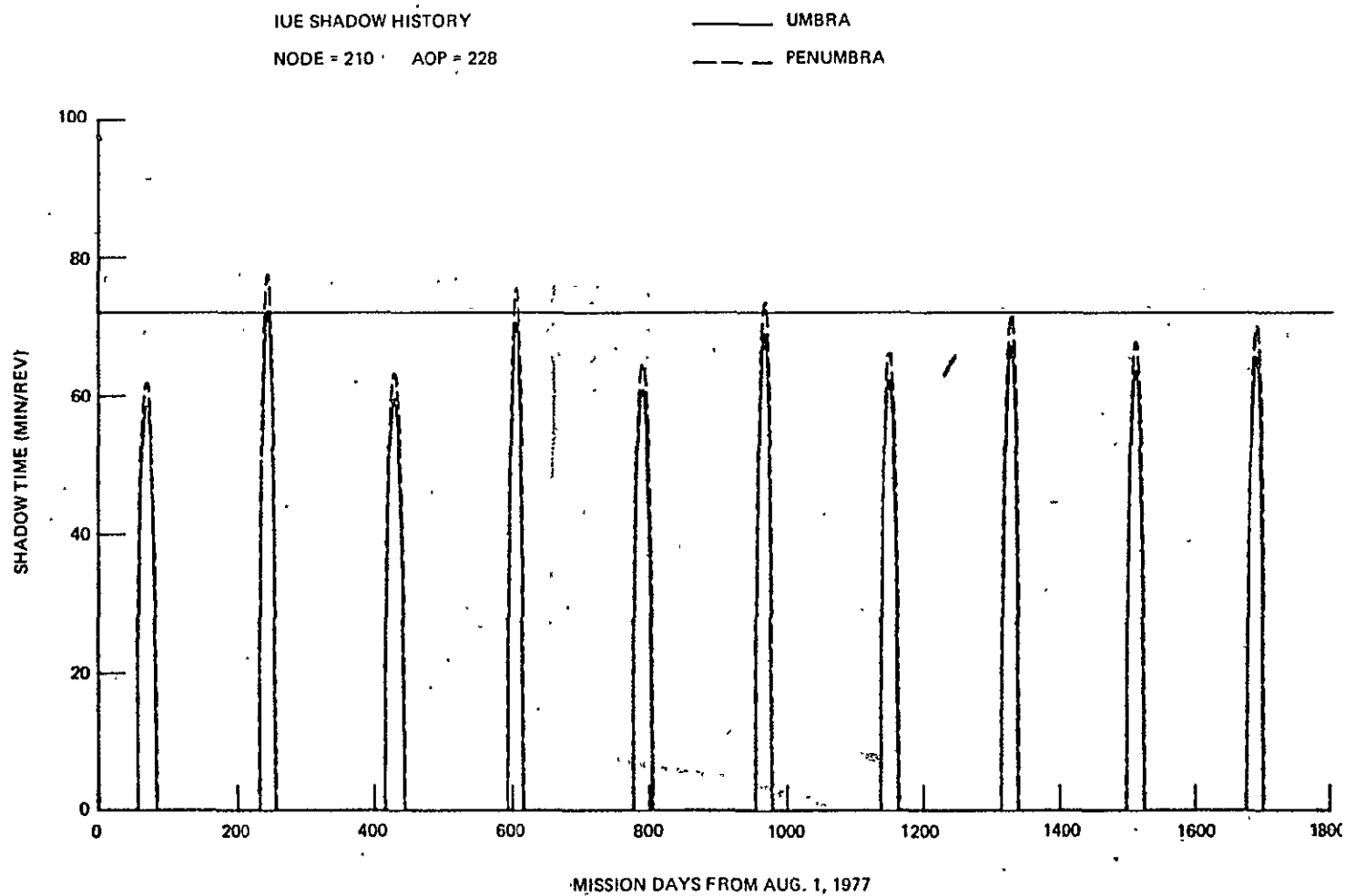


Figure 4-4. Synchronous Orbit Shadow for 99th Percentile Low Argument of Perigee and Node Angle 10 Degrees Below Nominal

_____ UMBRA
 _____ PENUMBRA

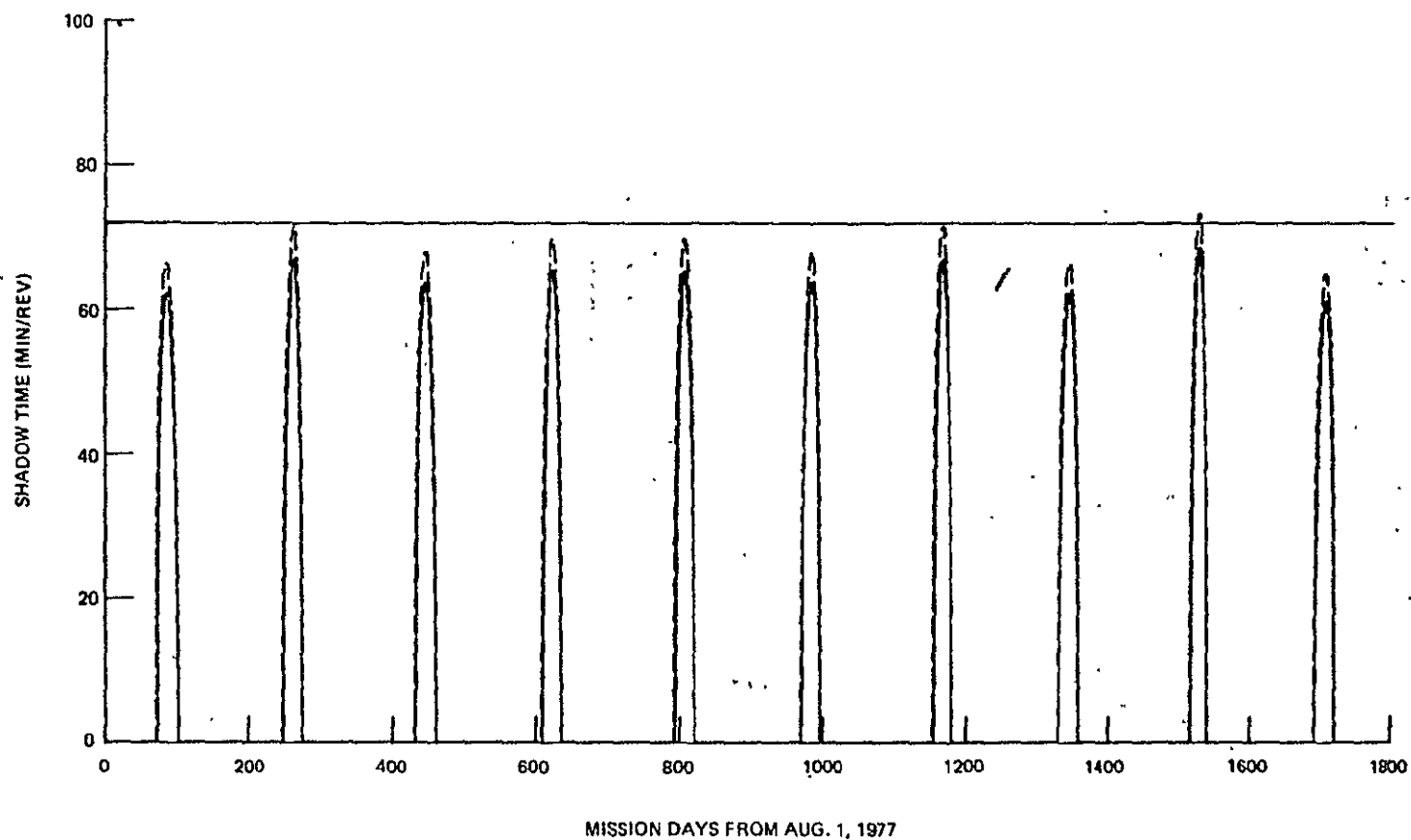


Figure 4-5. Synchronous Orbit Shadow for 99th Percentile Low Argument of Perigee and Node Angle 20 Degrees Above Nominal

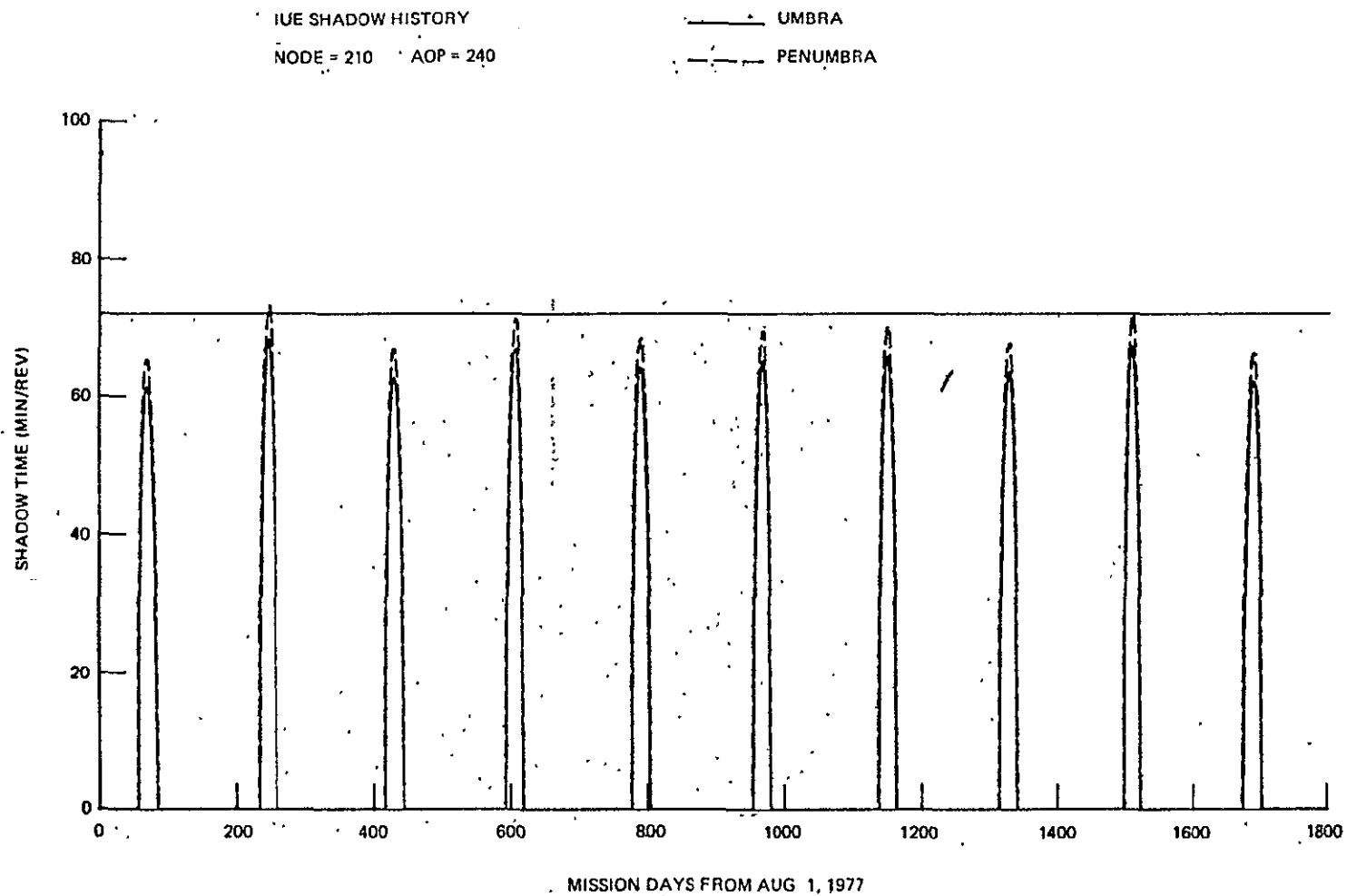


Figure 4-6. Synchronous Orbit Shadow for 99th Percentile High Argument of Perigee and Node Angle 10 Degrees Below Nominal

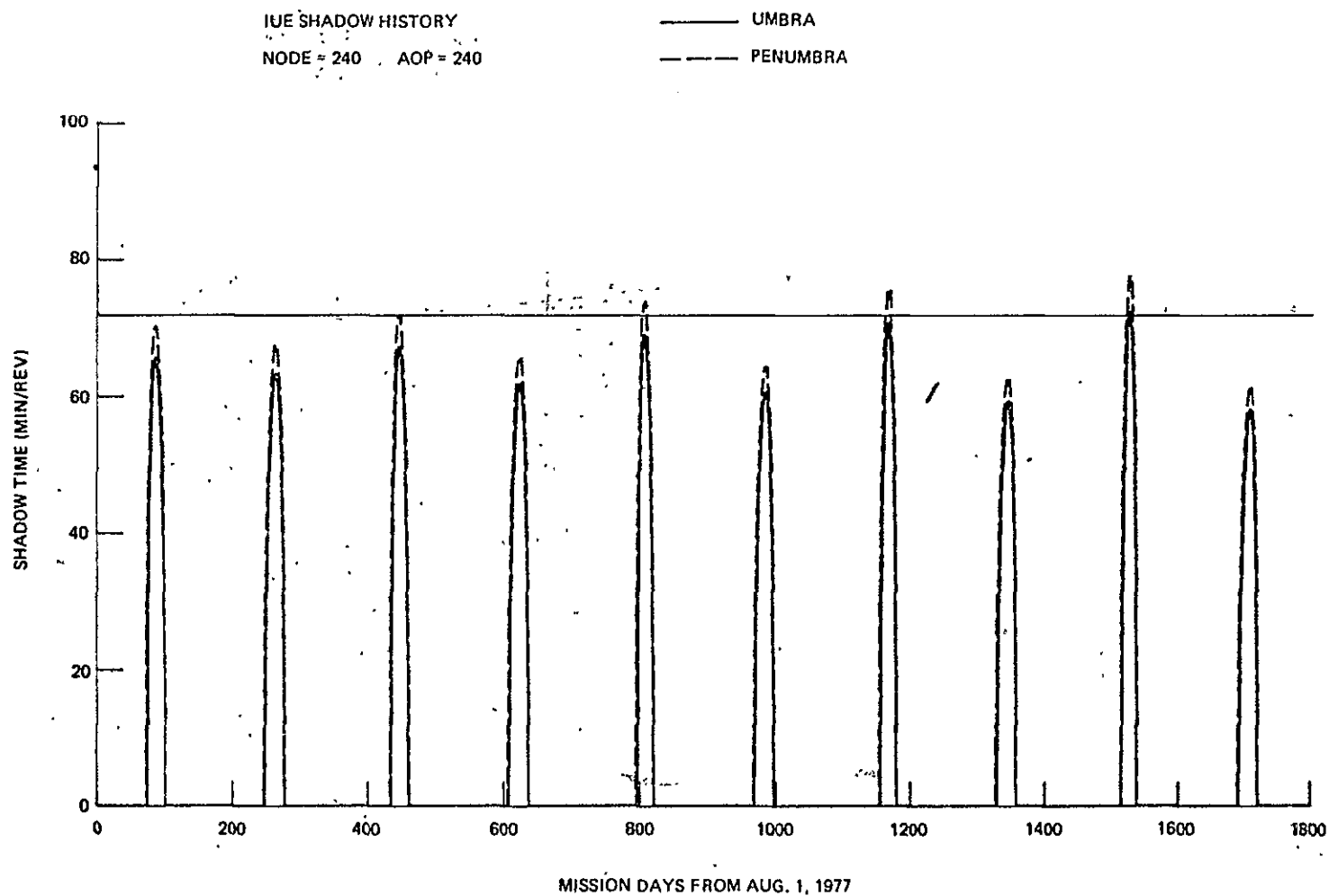


Figure 4-7. Synchronous Orbit Shadow for 99th Percentile High Argument of Perigee and Node Angle 20 Degrees Above Nominal

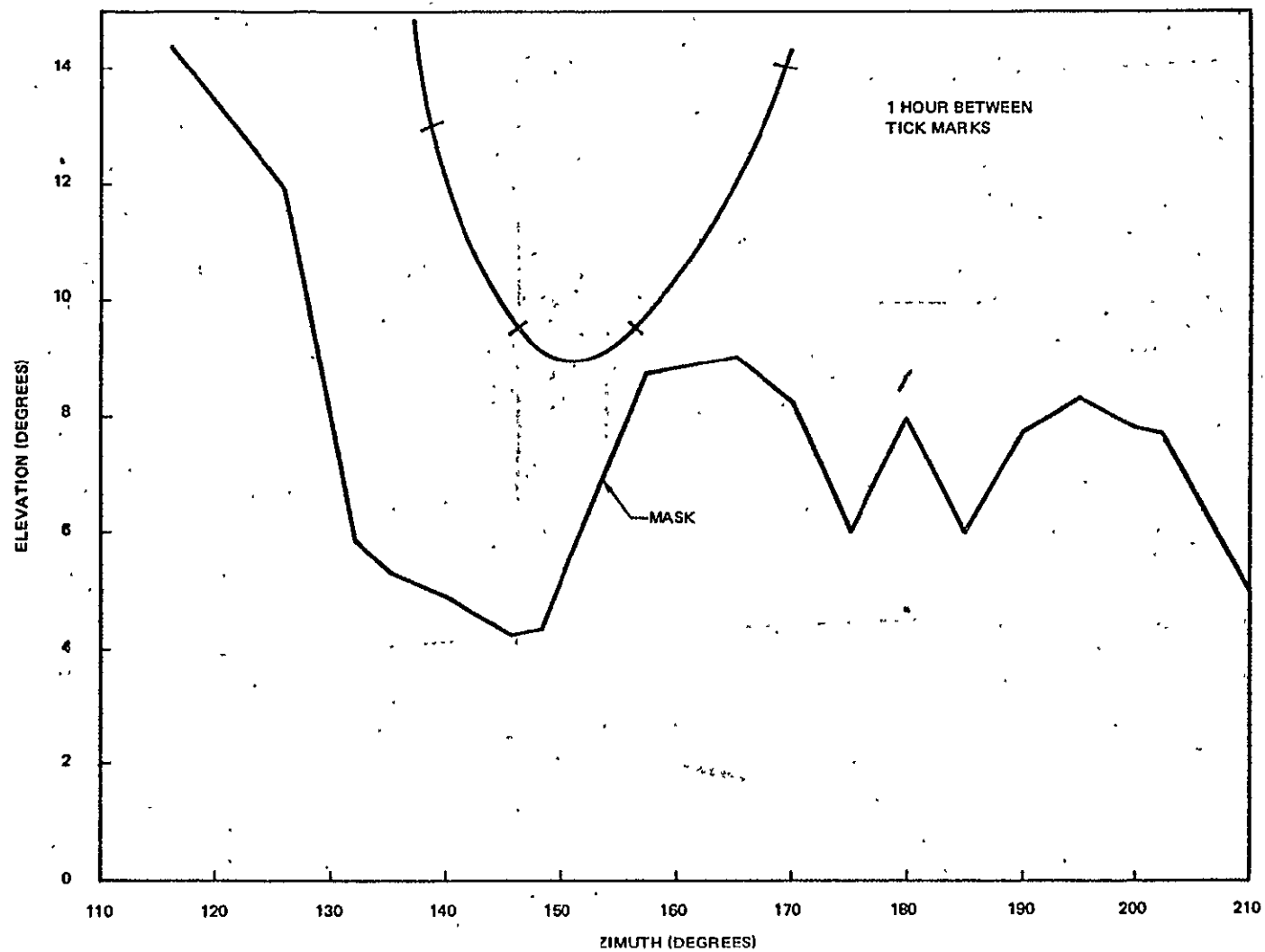


Figure 4-8. GSFC Tracking Mask and Nominal Tracking Pattern

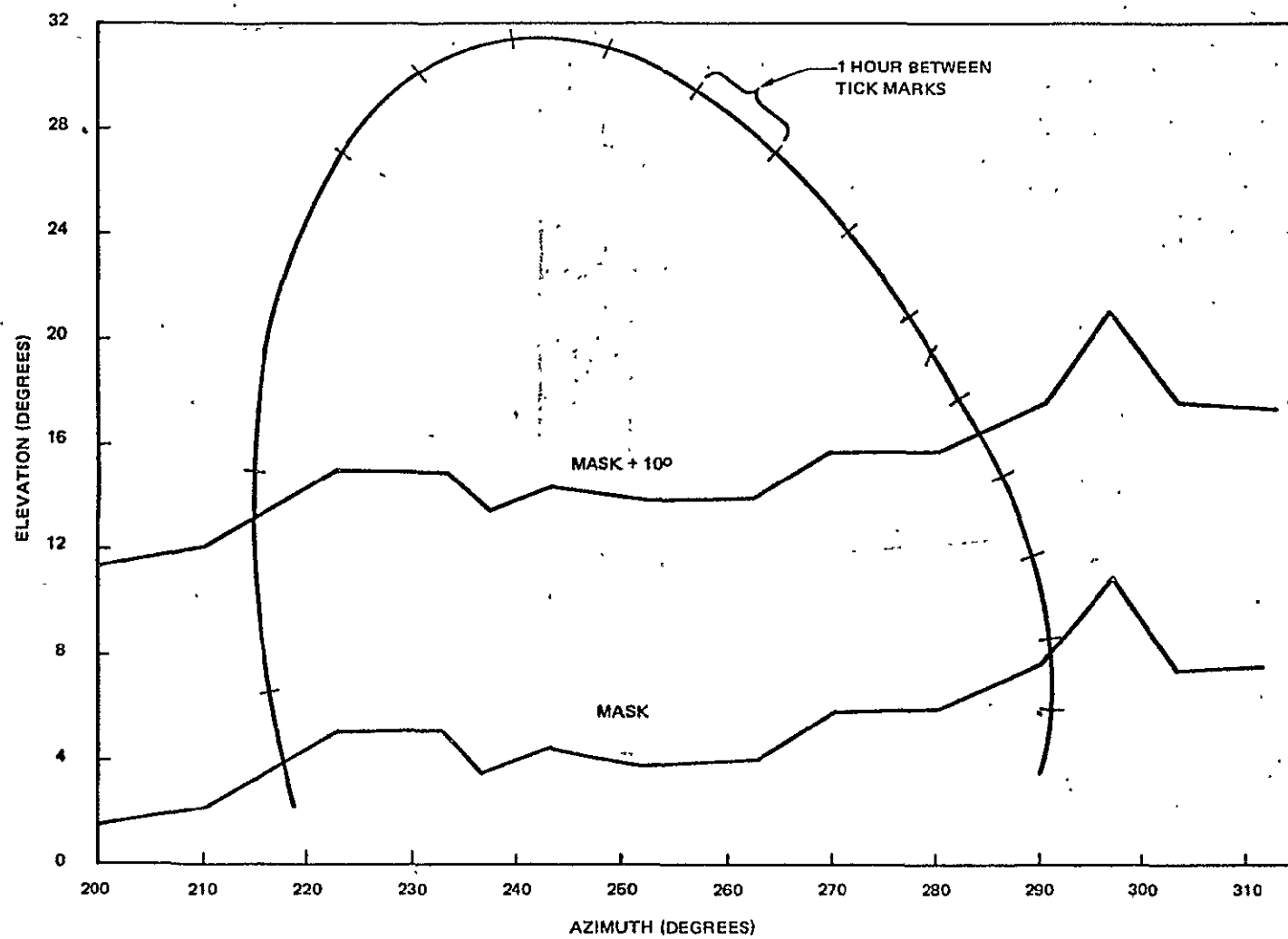


Figure 4-9. VILFRA Tracking Mask and Nominal Tracking Pattern

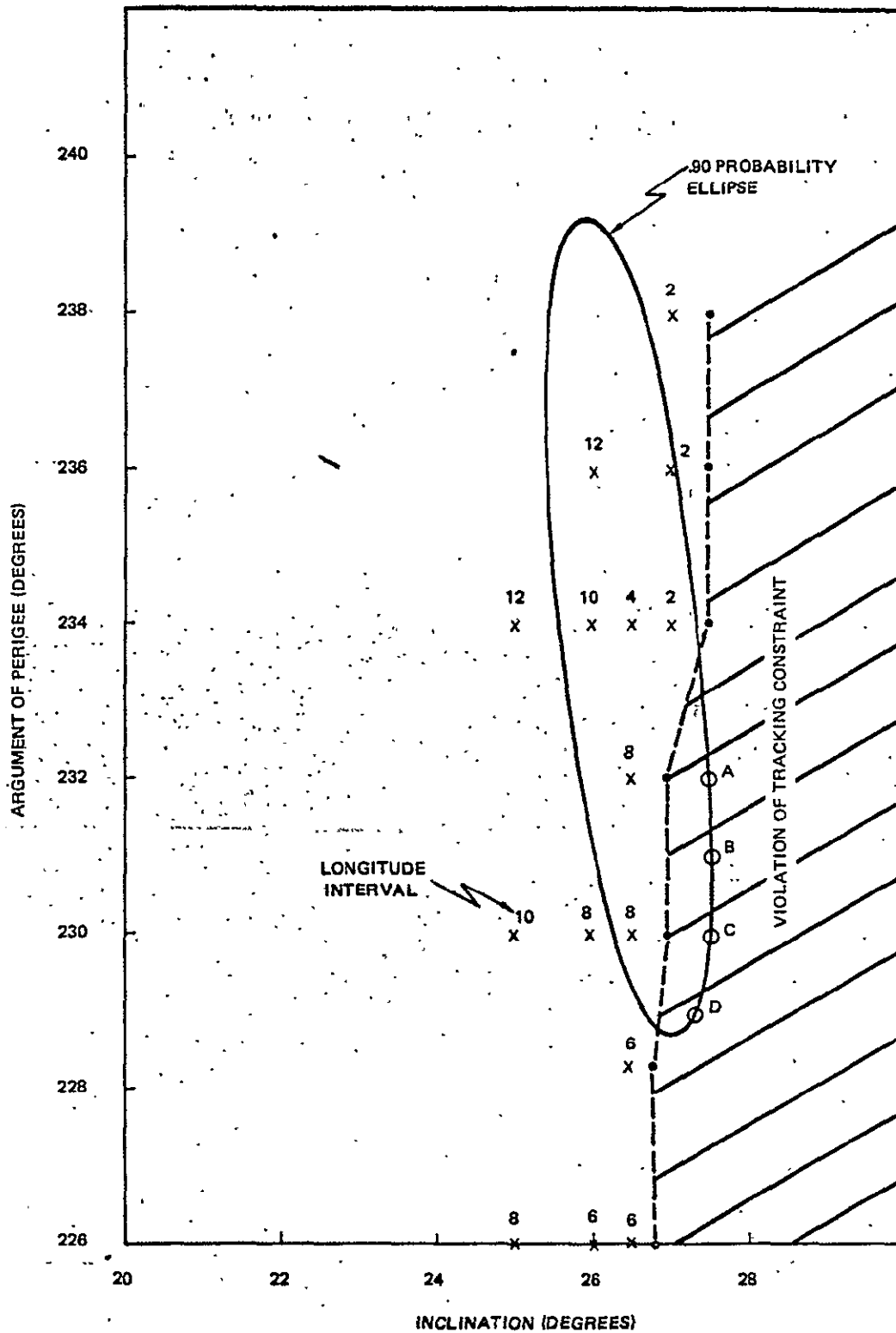


Figure 4-10. Longitude Intervals for Acceptable Tracking Coverage

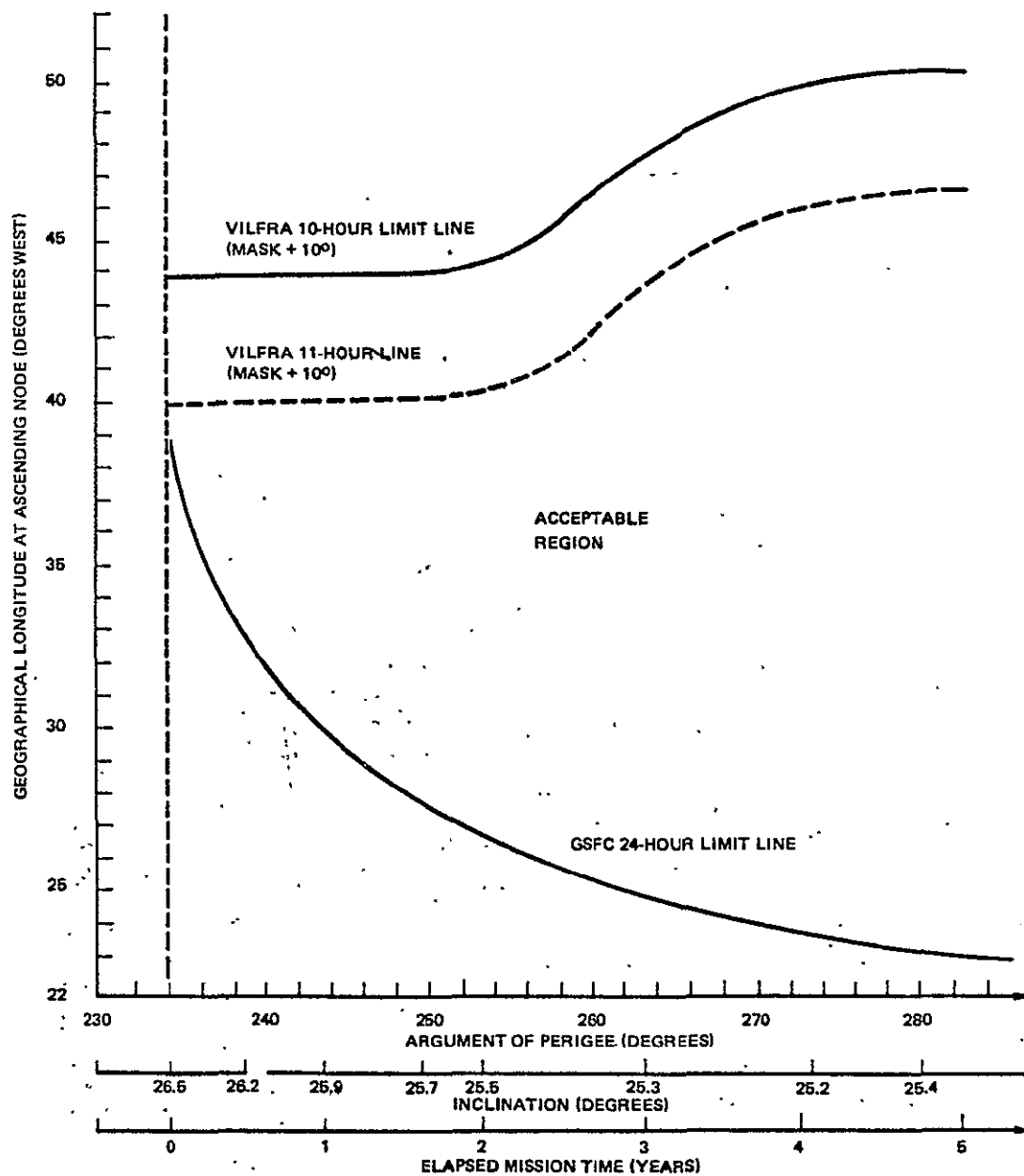


Figure 4-11. Stationkeeping Limits for Nominal Orbit

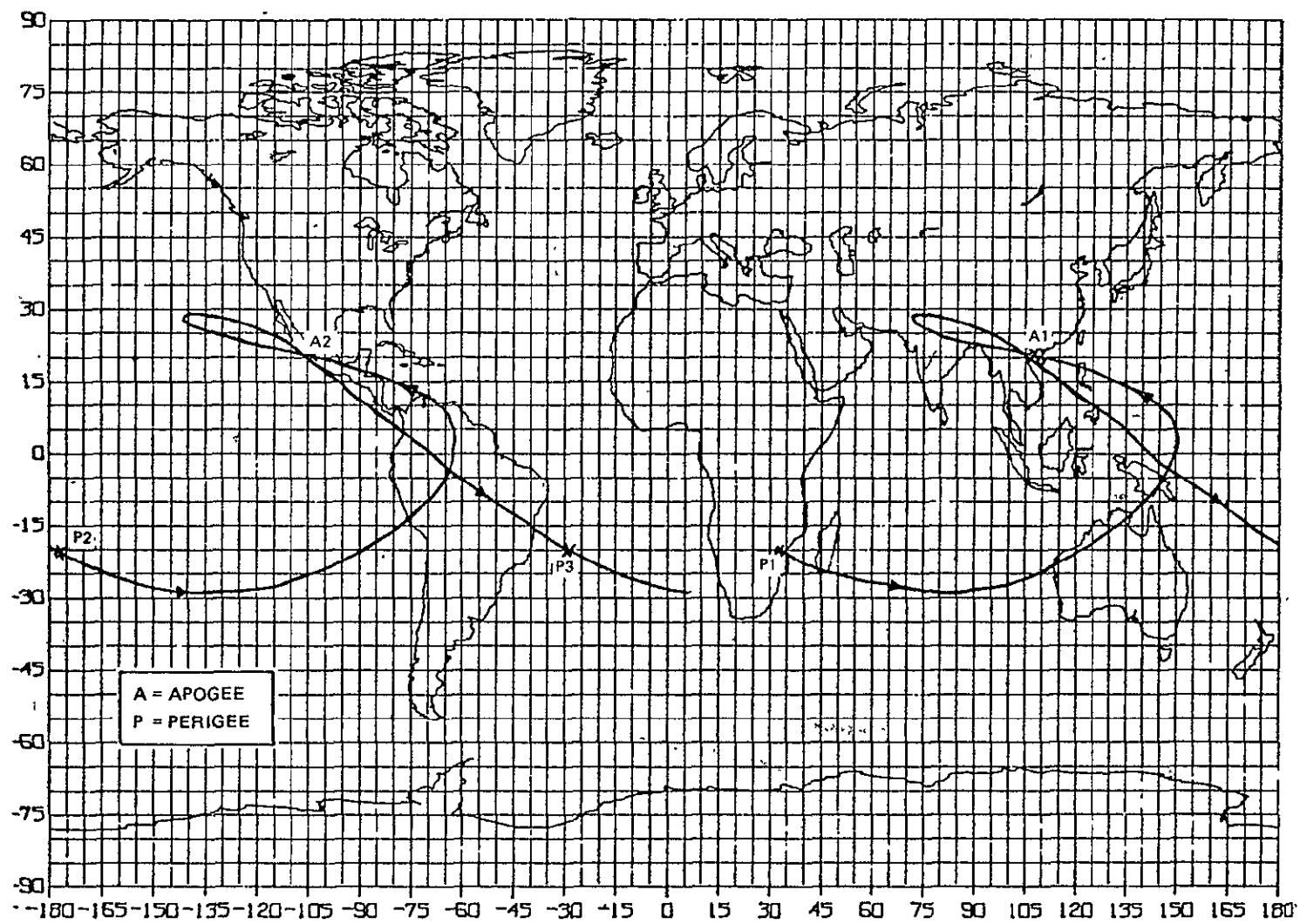


Figure 4-12. Groundtrack for Transfer Orbit (Apogee 1 and 2)

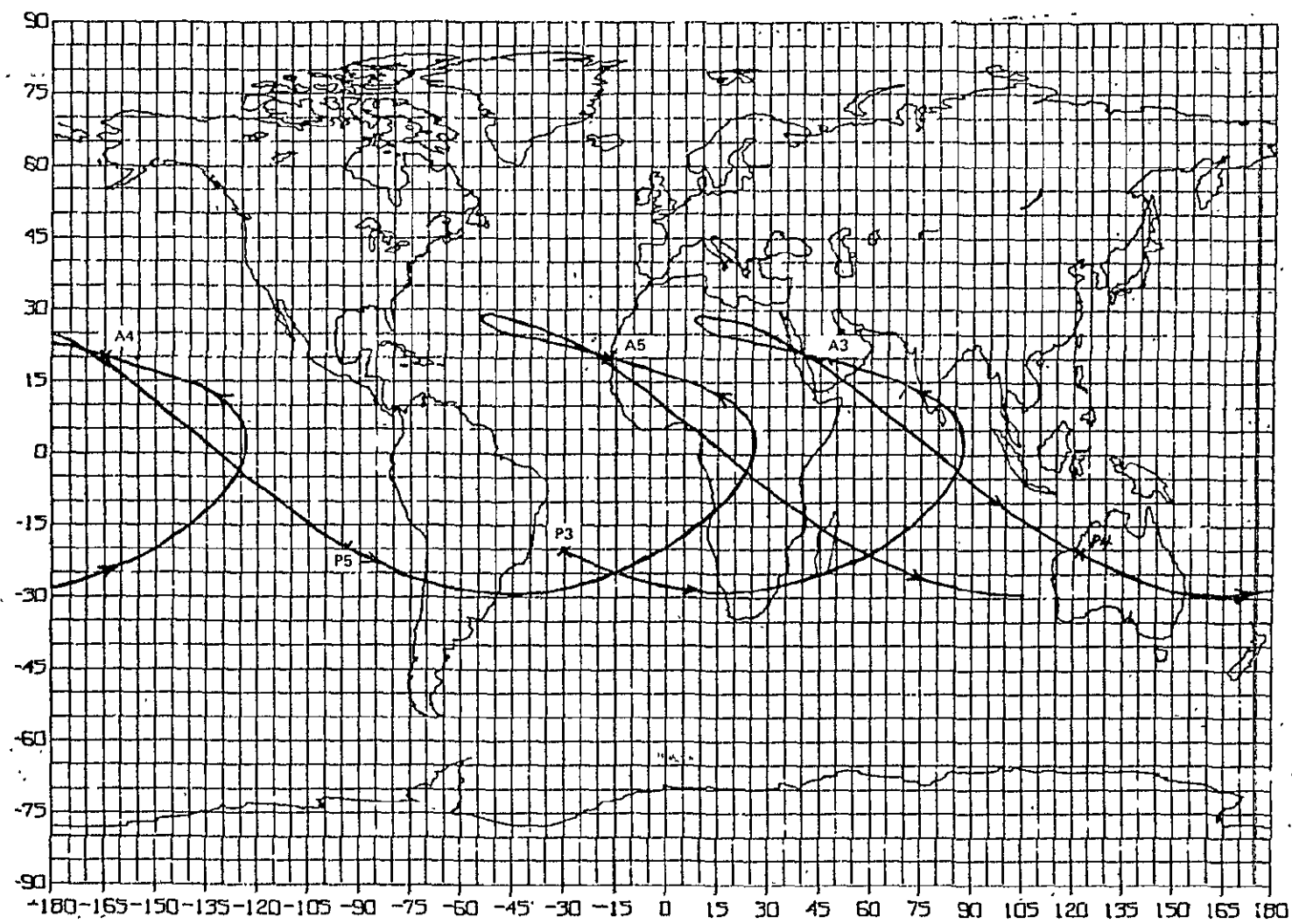


Figure 4-13. Groundtrack for Transfer Orbit (Apogee 3, 4, and 5)

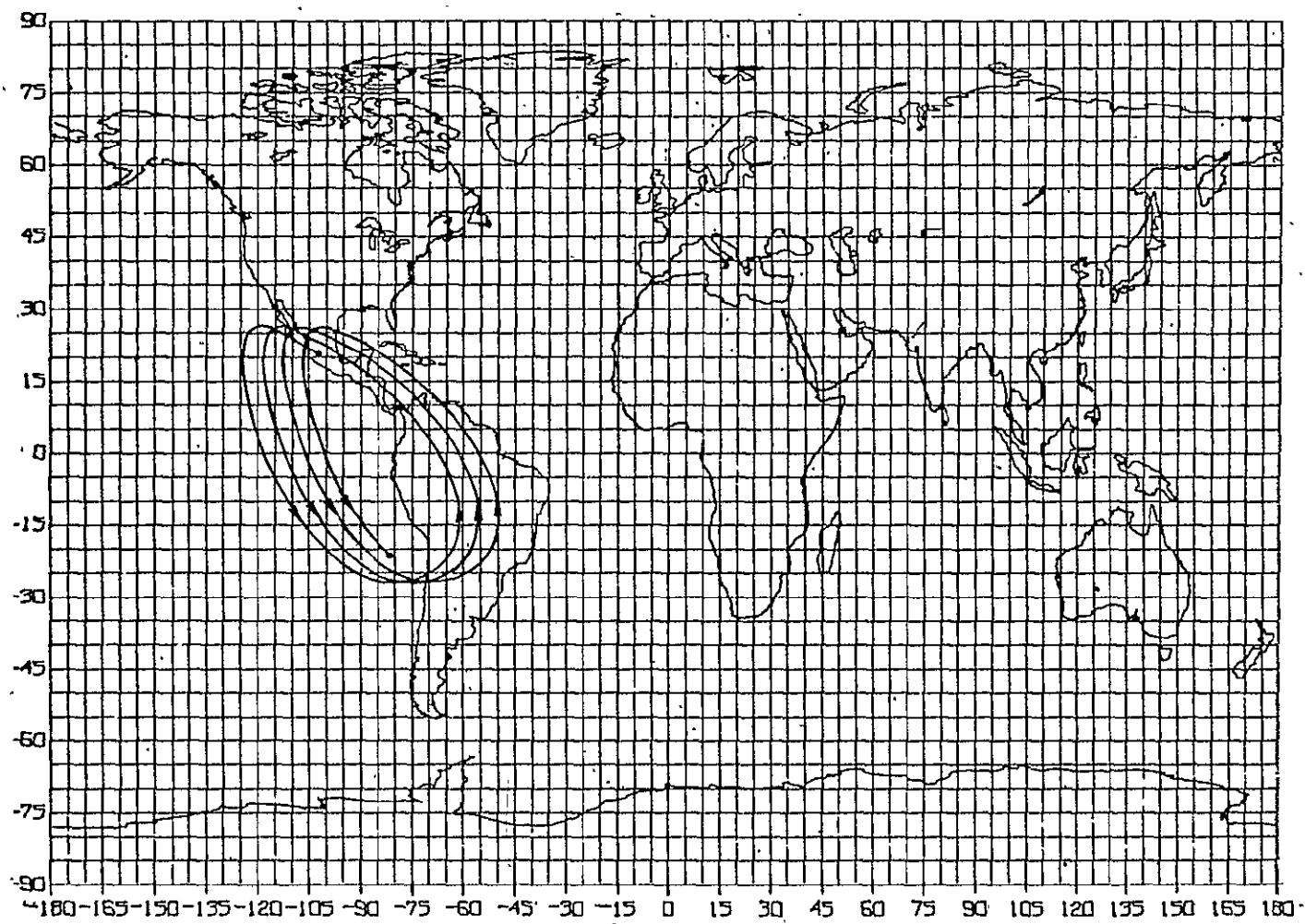


Figure 4-14. Groundtrack for Drift Orbit Phase 1

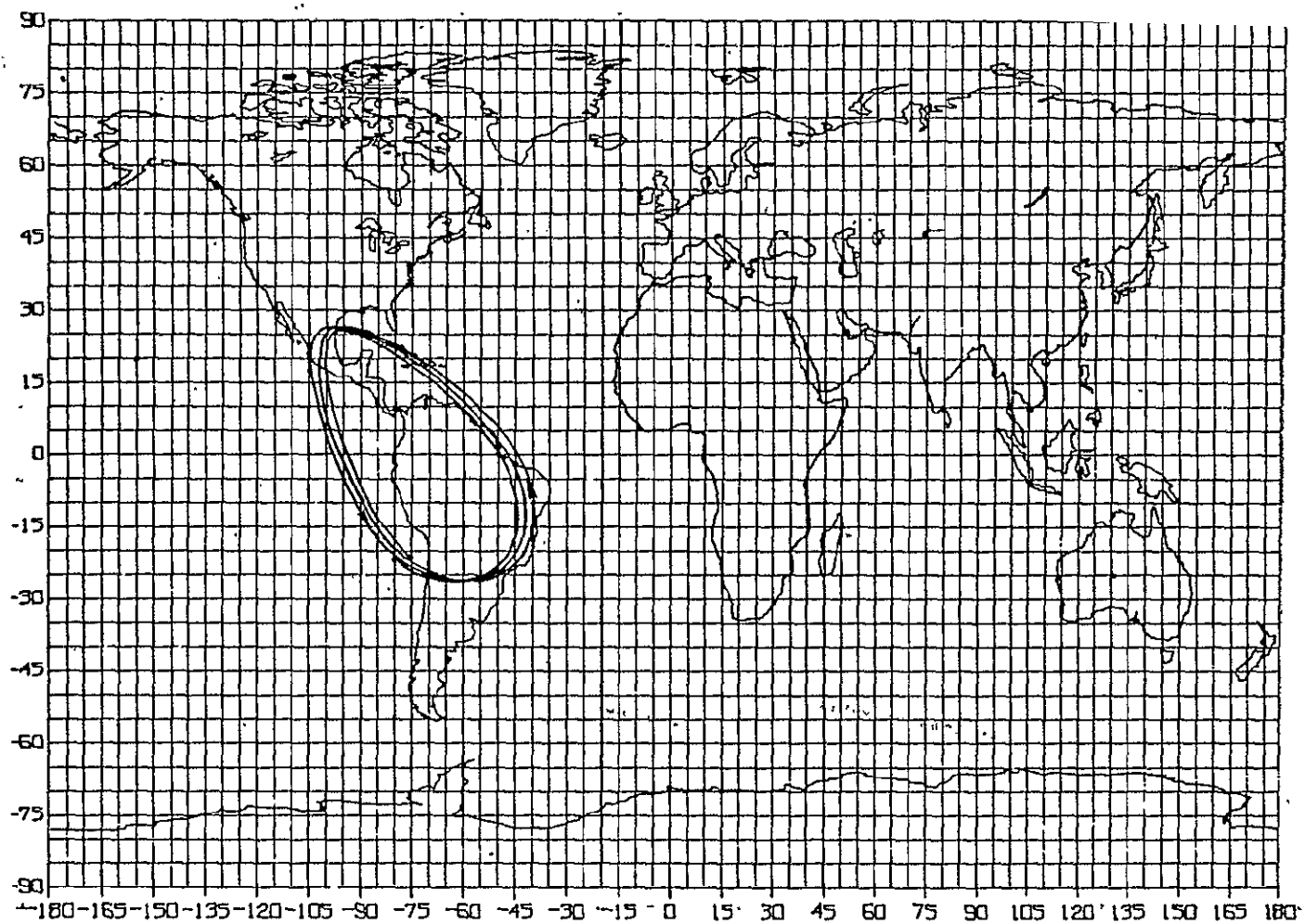


Figure 4-15. Groundtrack for Drift Orbit Phase 2

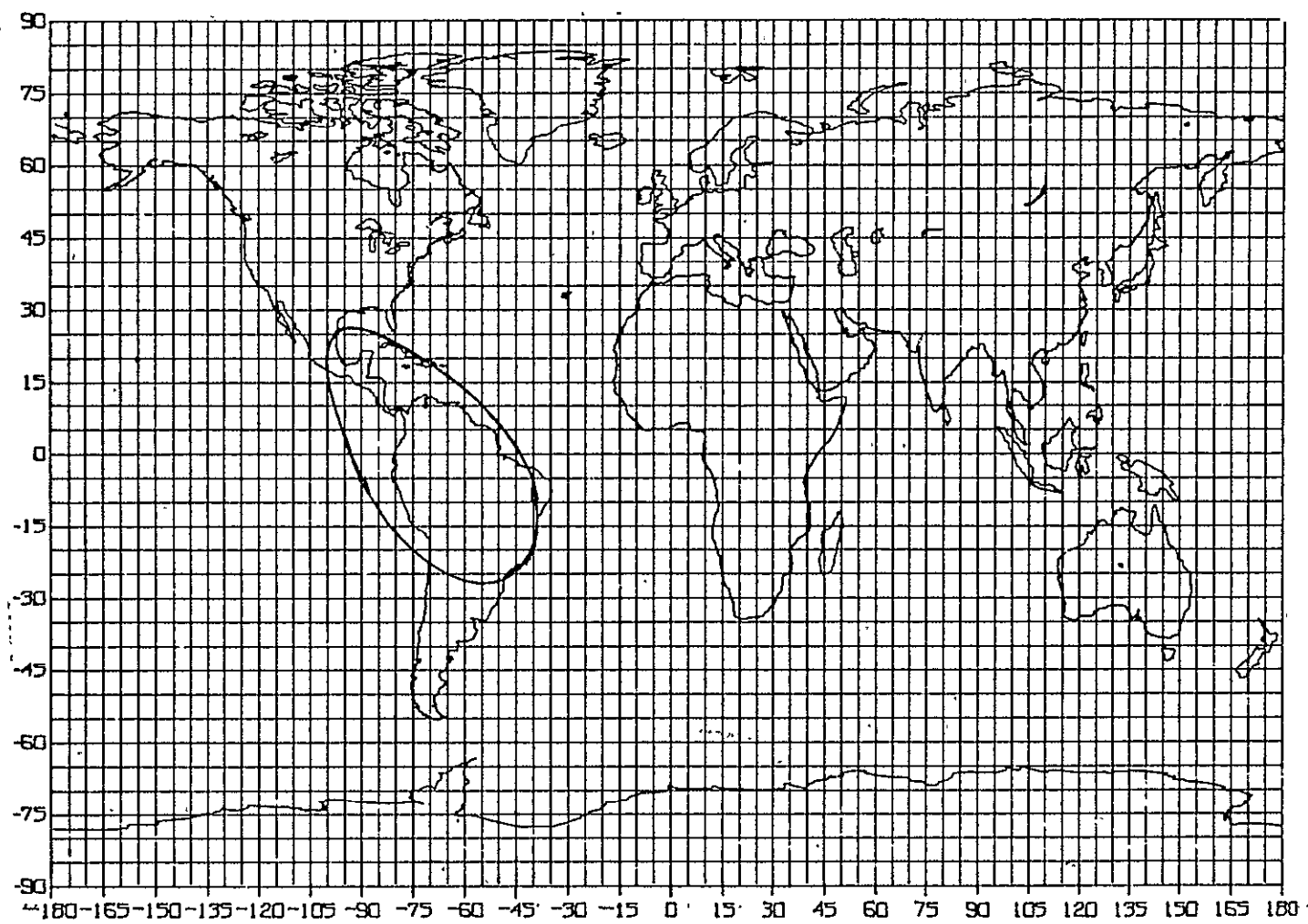


Figure 4-16. Groundtrack for Drift Orbit Phase 3

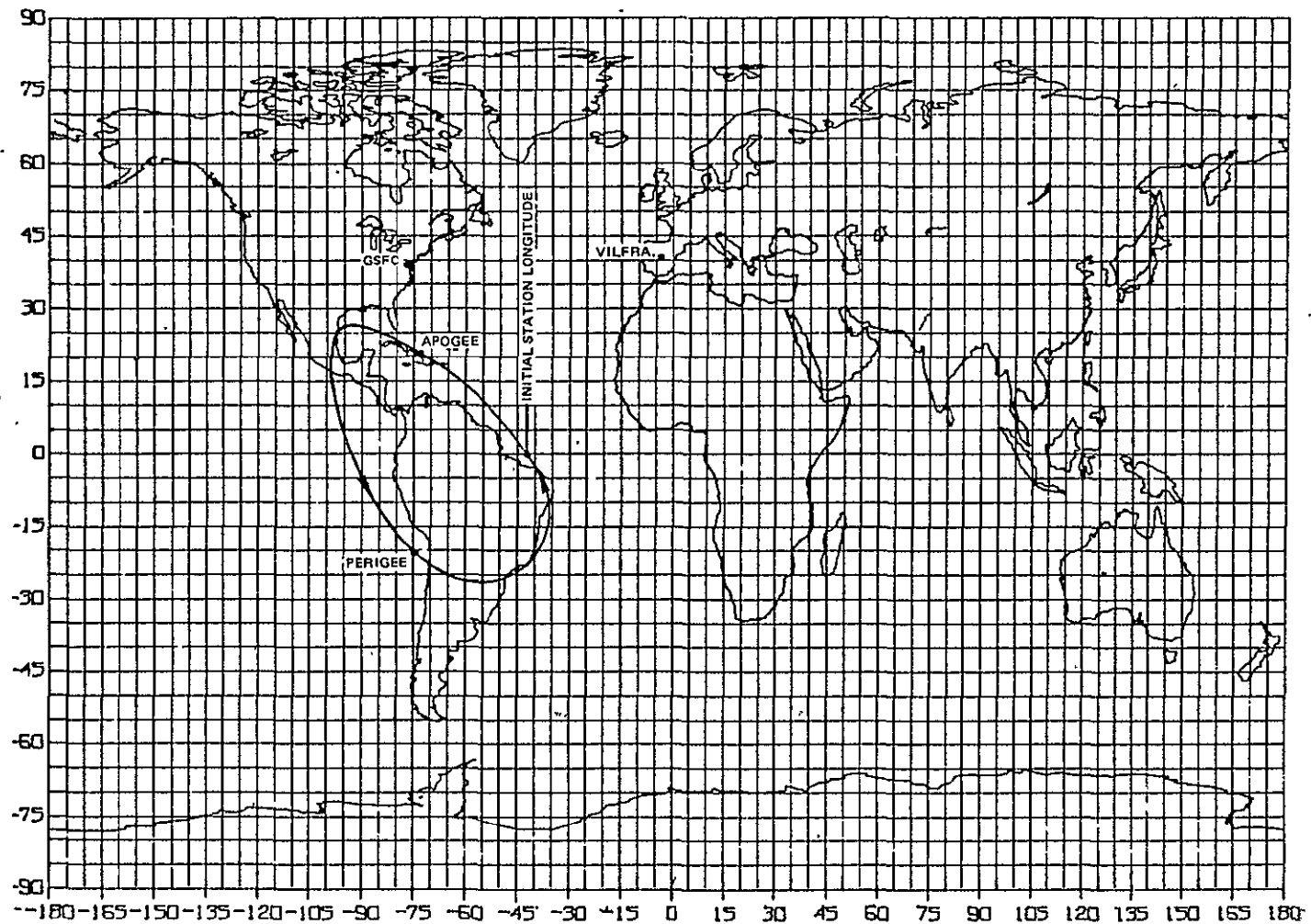


Figure 4-17. Groundtrack for Synchronous Orbit

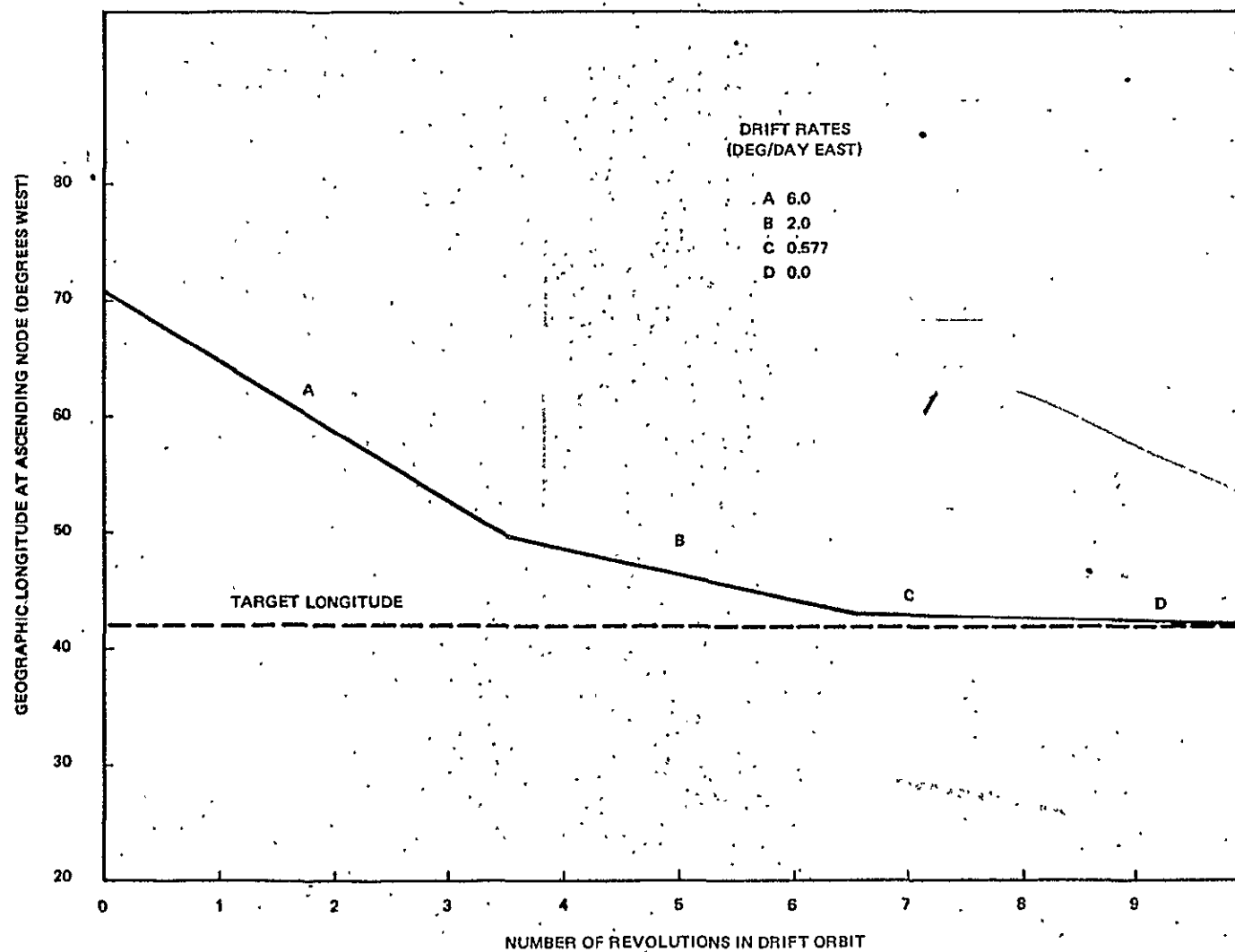


Figure 4-18. Station Acquisition

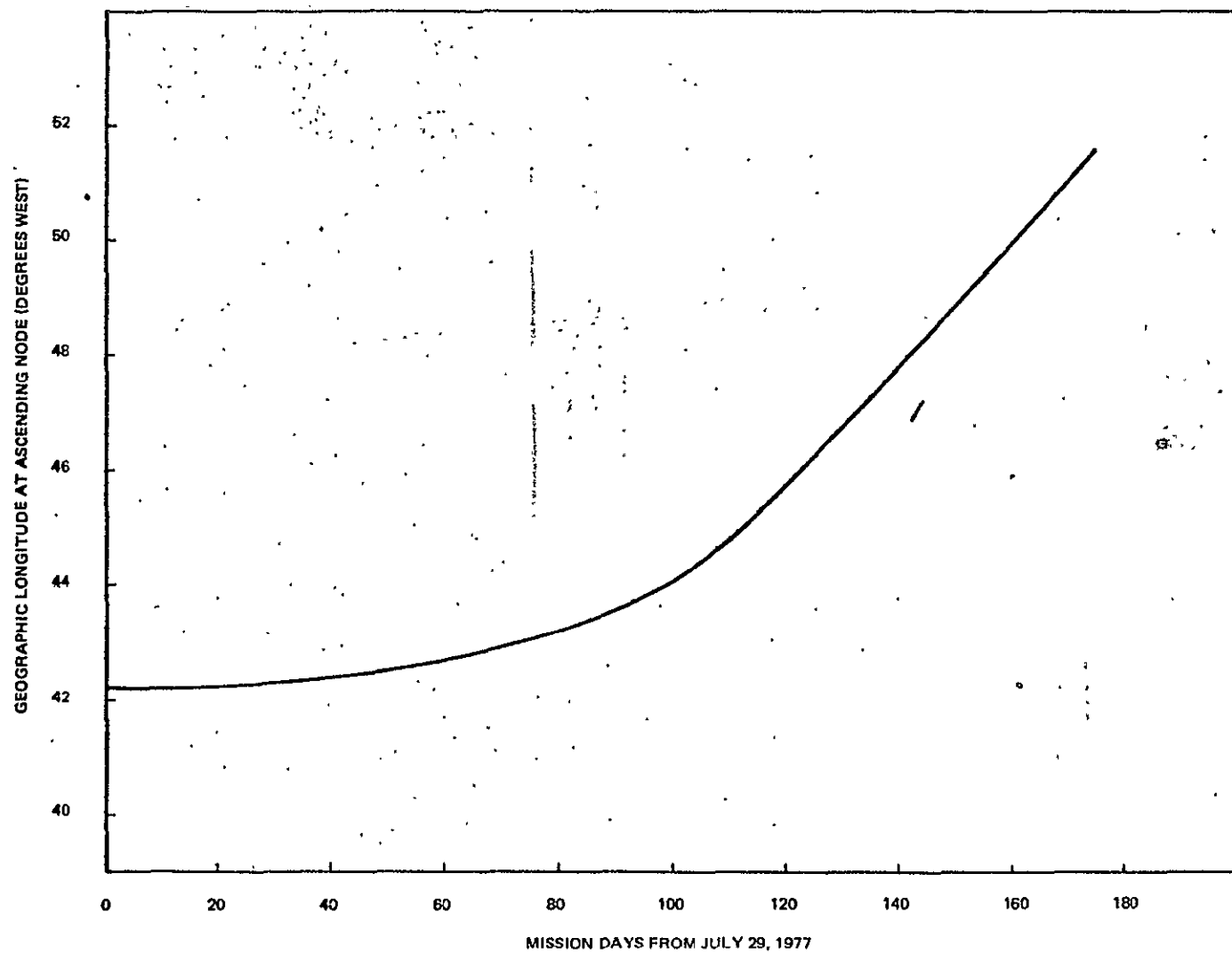


Figure 4-19. Evolution of Longitude at Ascending Node

APPENDIX A - PARAMETER HISTOGRAMS

This appendix presents the histograms generated using the Monte Carlo option in the TBERR Program. The parameters for which histograms are provided are

1. Drift orbit semimajor axis
2. Drift orbit eccentricity
3. Drift orbit inclination
4. Drift orbit node
5. Drift orbit argument of perigee
6. Drift orbit true anomaly
7. Drift orbit perigee radius
8. Drift orbit apogee radius
9. Post-AMF velocity to acquire station
10. Drift rate
11. On station weight
12. Hydrazine used to acquire station
13. Velocity required to correct semimajor axis and eccentricity
14. Hydrazine used to correct semimajor axis and eccentricity
15. Velocity required to correct drift rate errors
16. Hydrazine used to correct drift rate errors
17. Synchronous orbit eccentricity

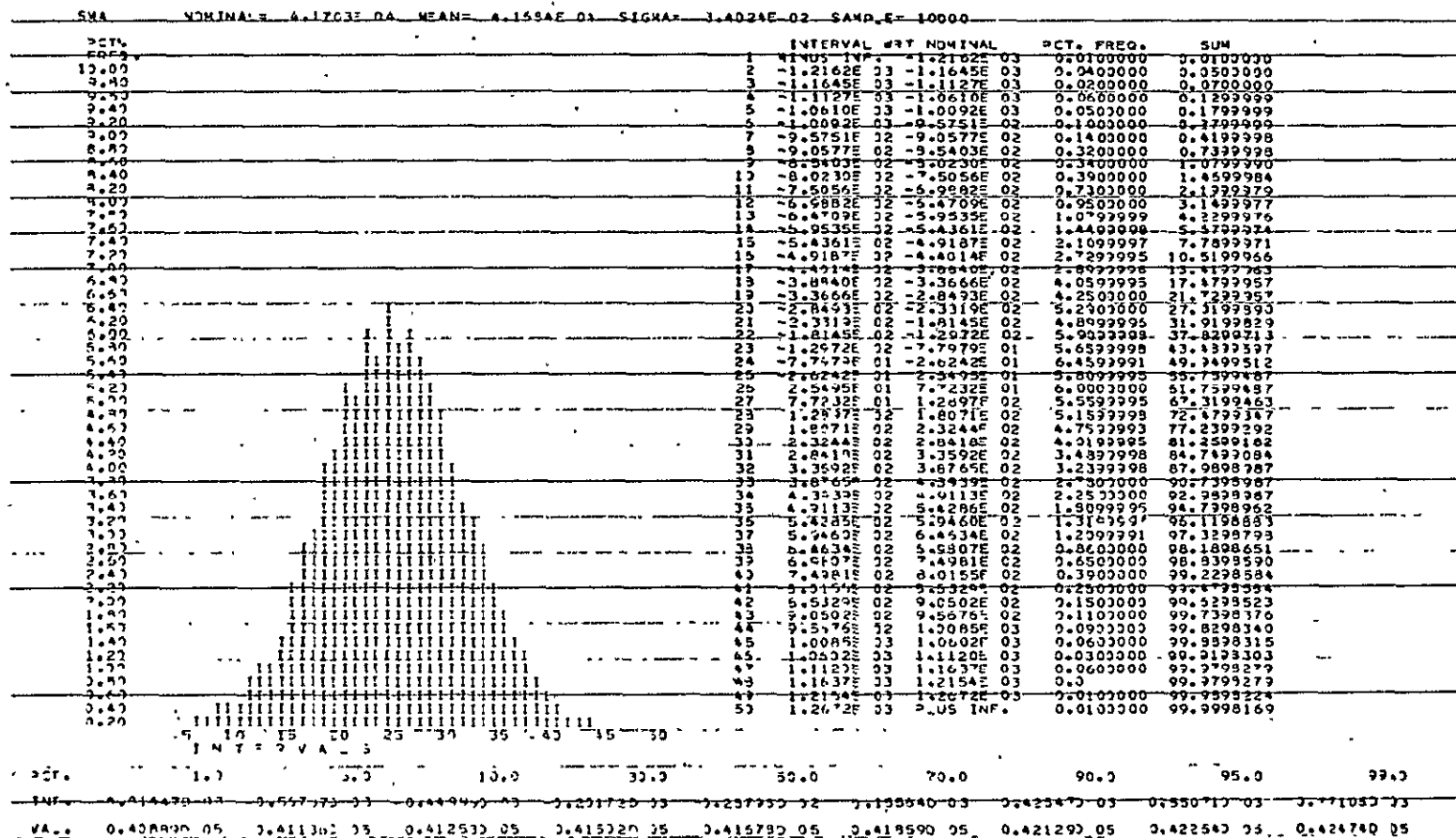


Figure A-1. Drift Orbit Semimajor Axis Histogram (Kilometers)

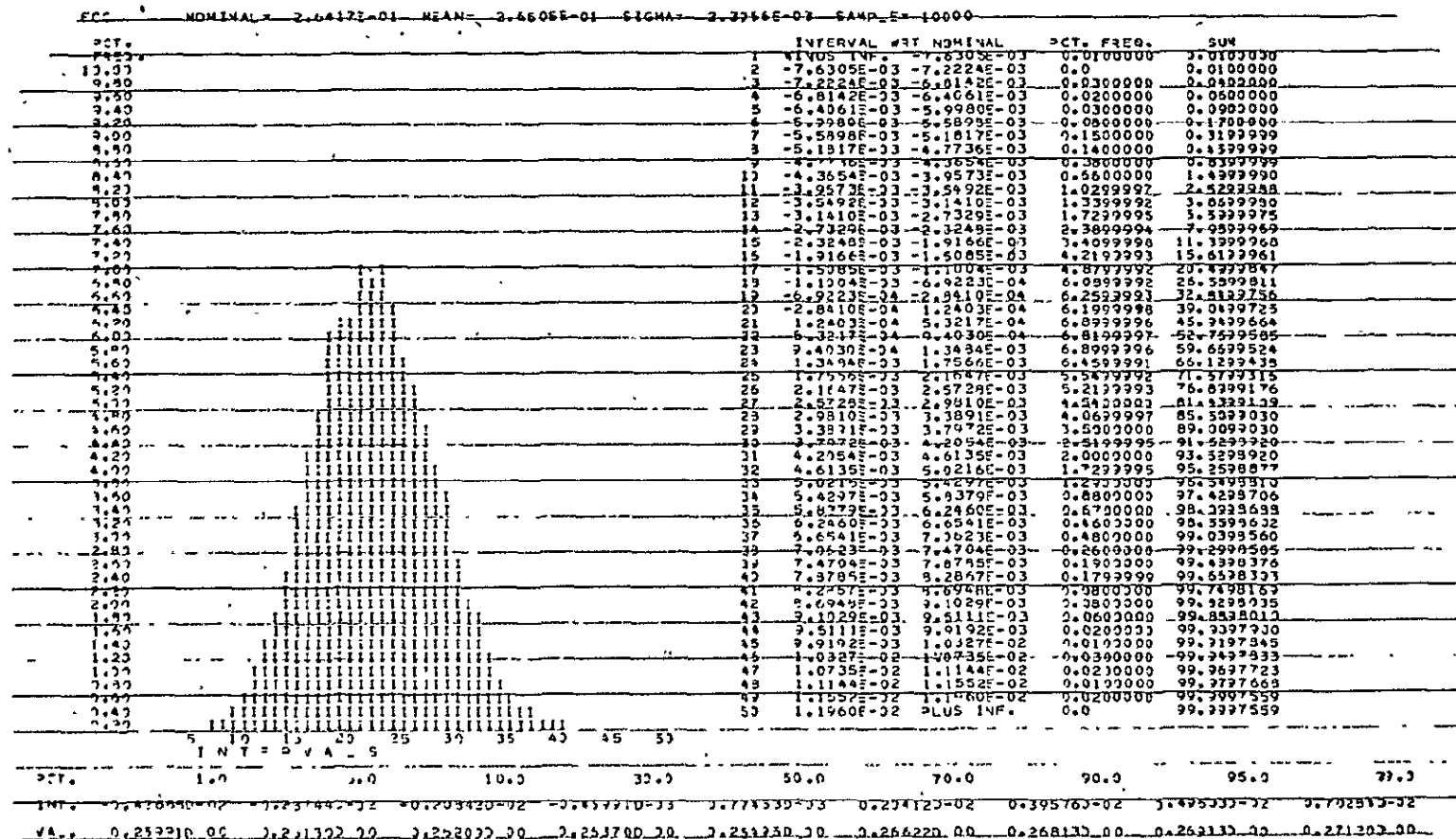


Figure A-2.. Drift Orbit Eccentricity Histogram

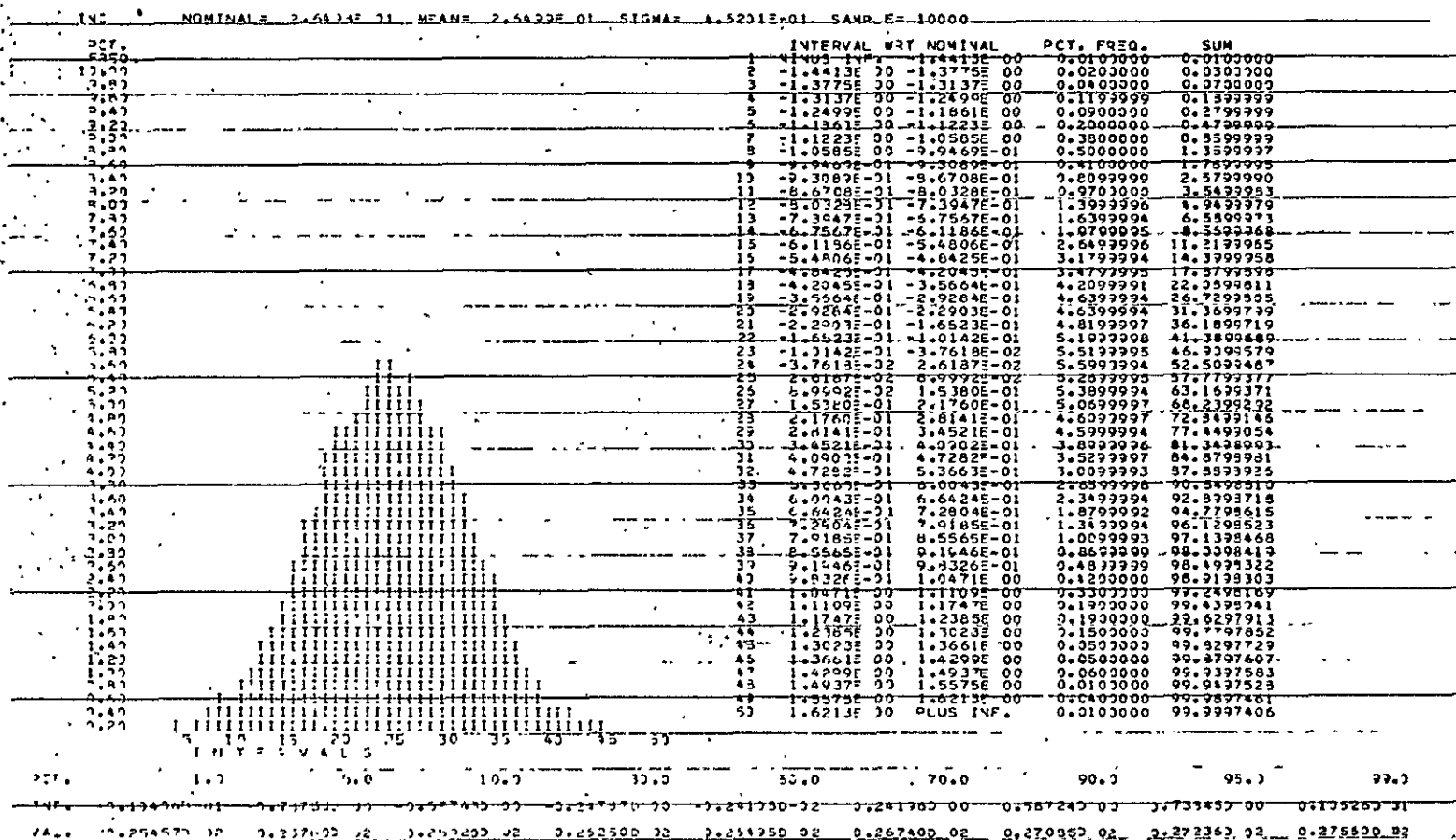


Figure A-3. Drift Orbit Inclination Histogram (Degrees)

A-5

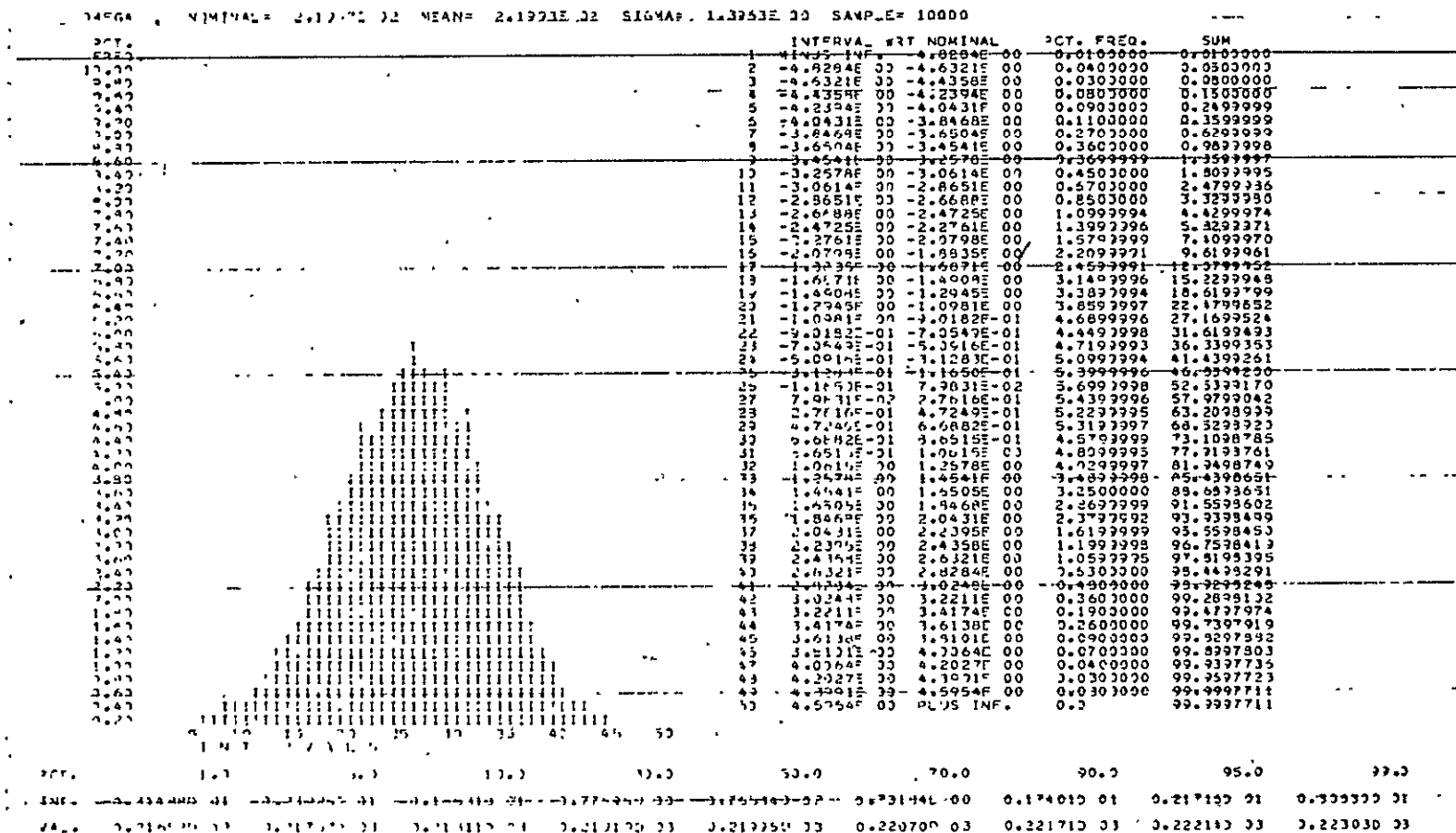


Figure A-4. Drift Orbit Node Histogram (Degrees)

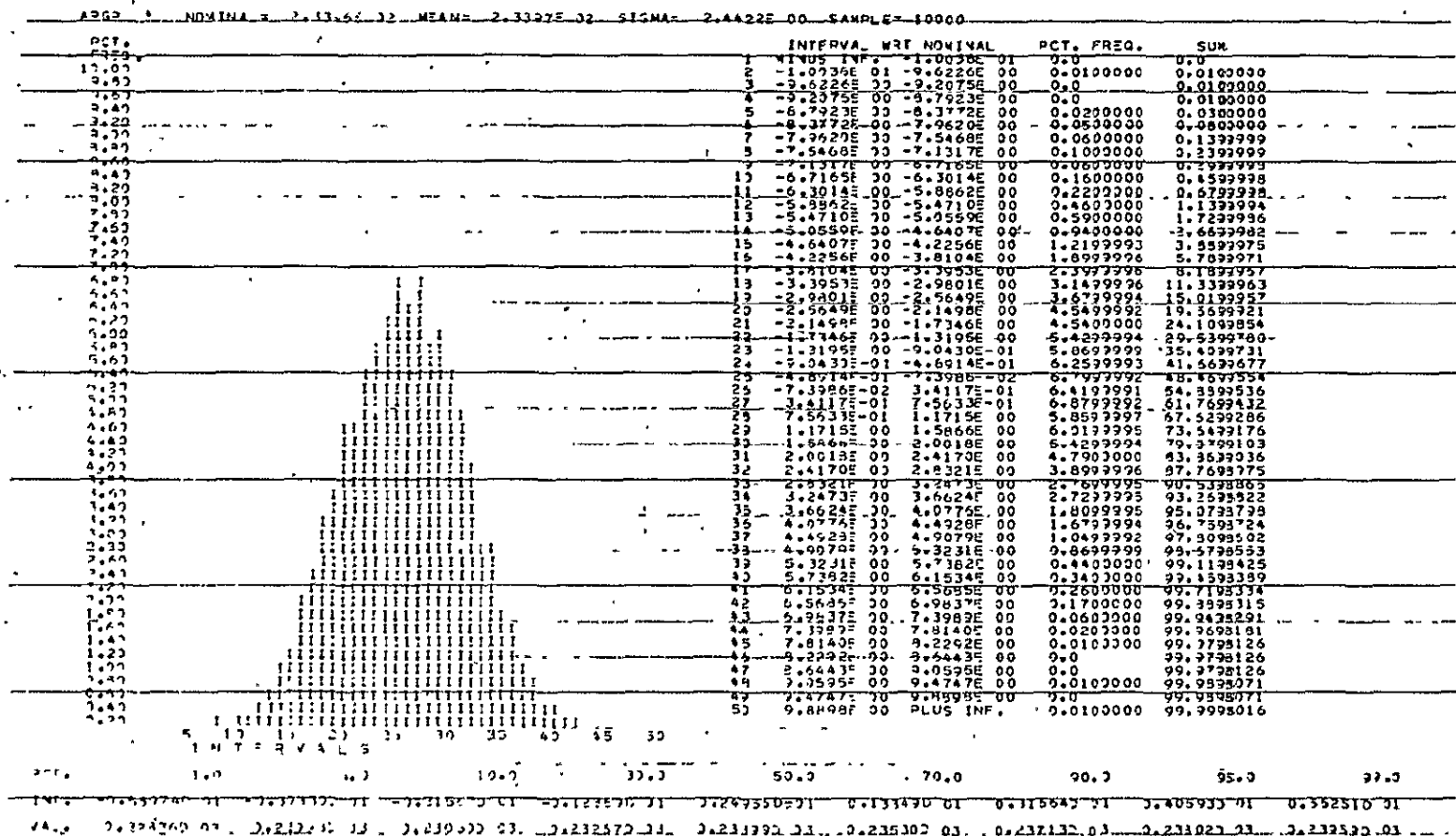
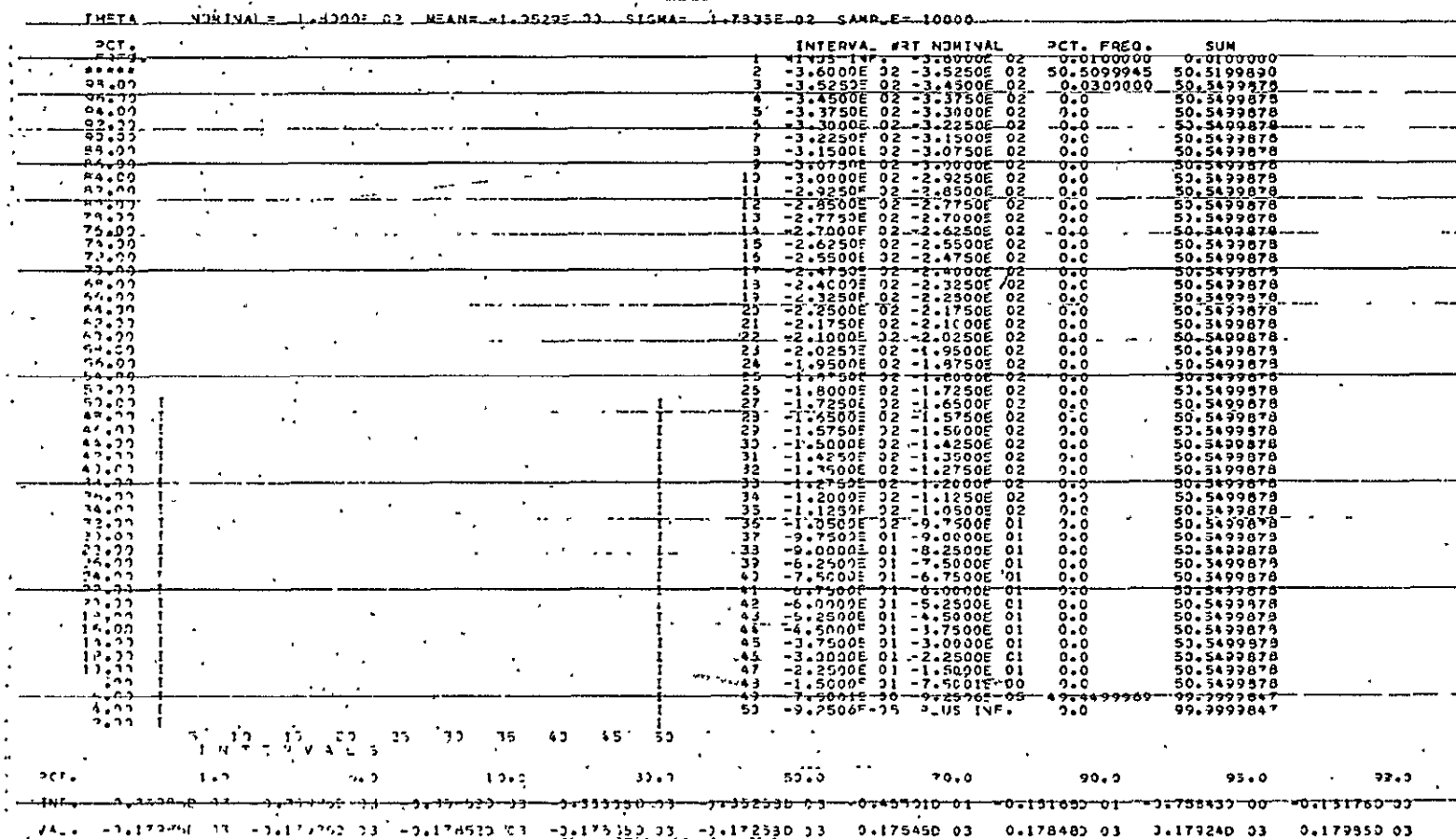


Figure A-5. Drift Orbit Argument of Perigee Histogram (Degrees)

A-7



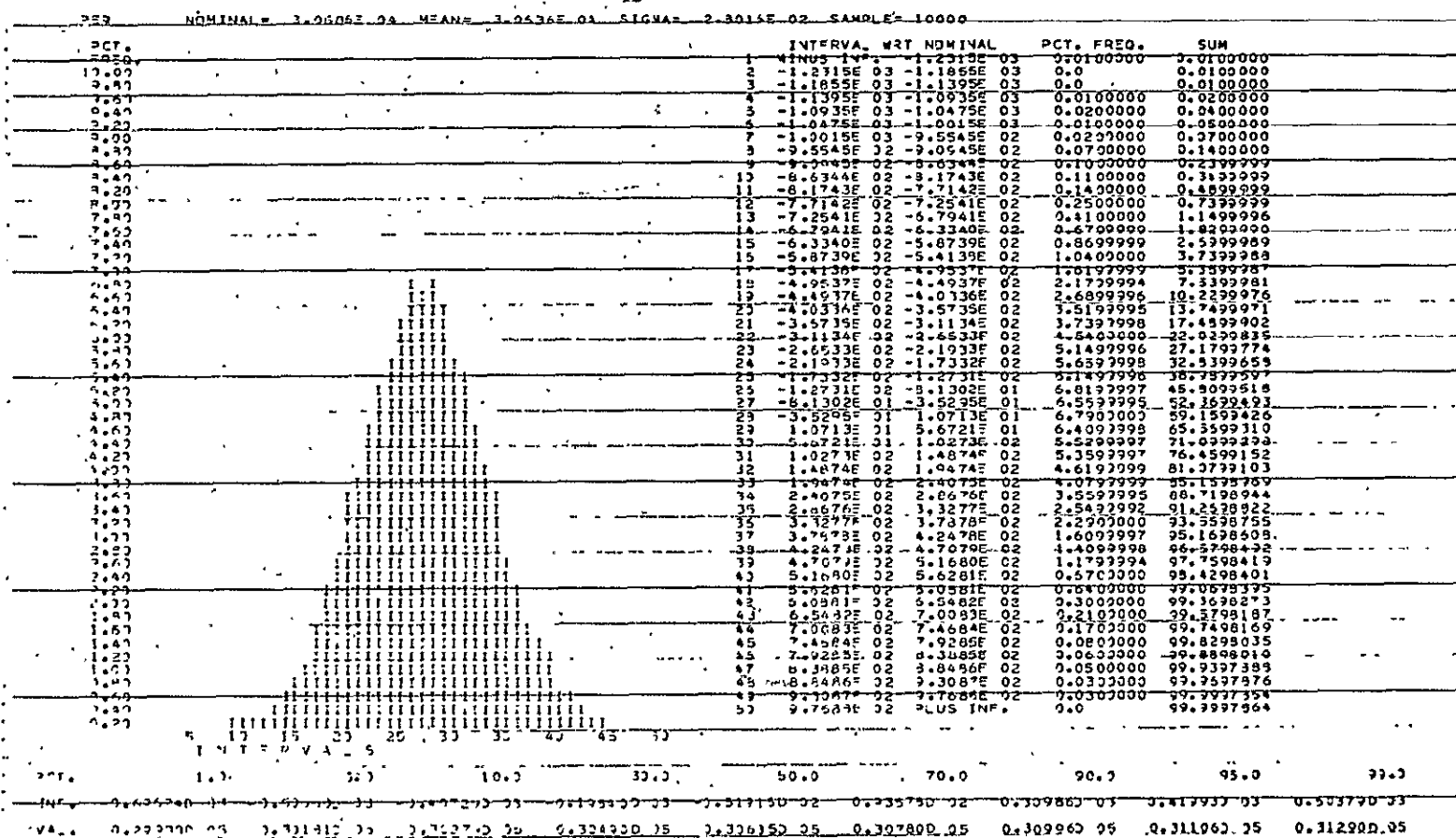


Figure A-7. Drift Orbit Perigee Radius Histogram (Kilometers)

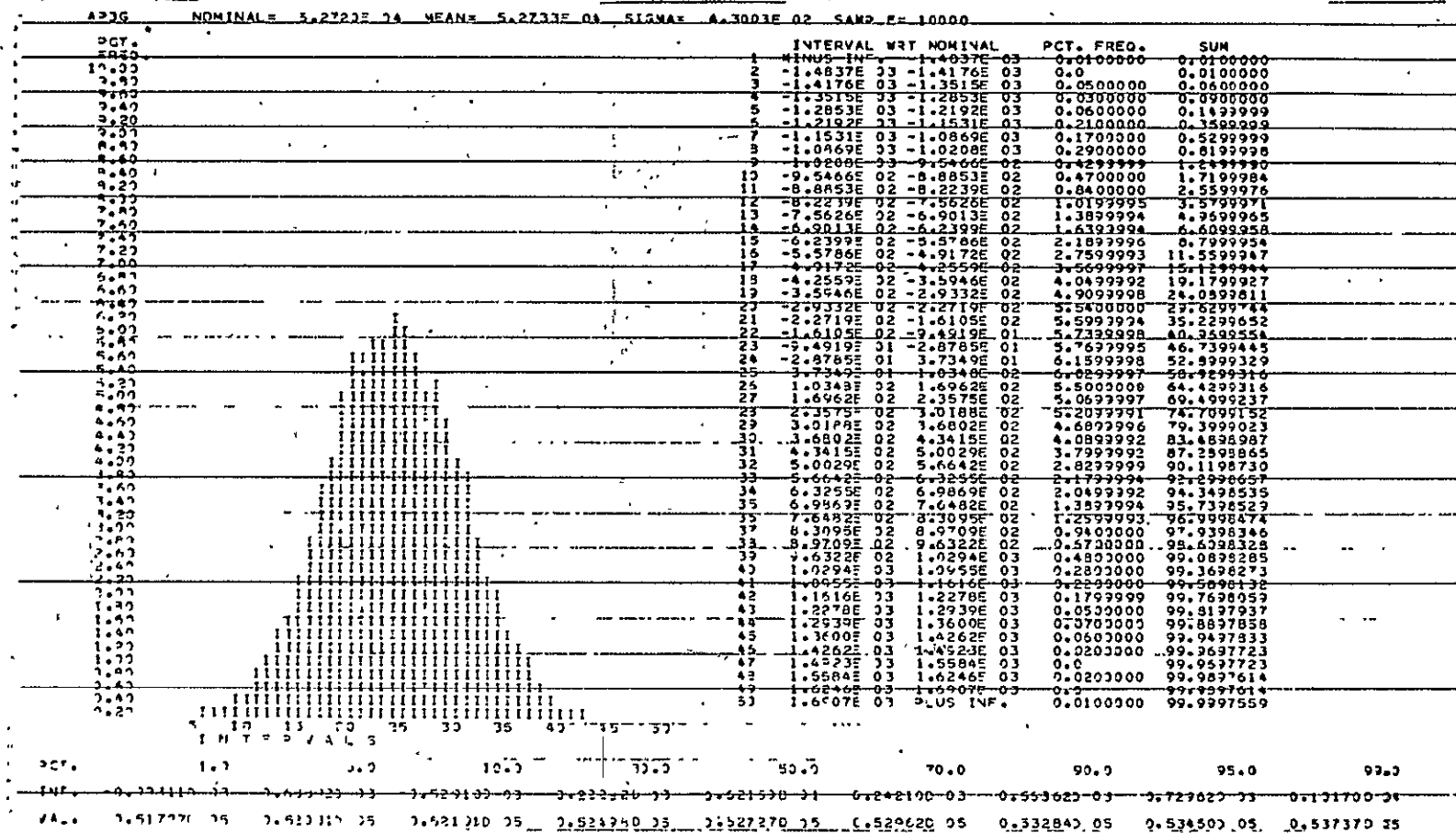


Figure A-8. Drift Orbit Apogee Radius Histogram (Kilometers)

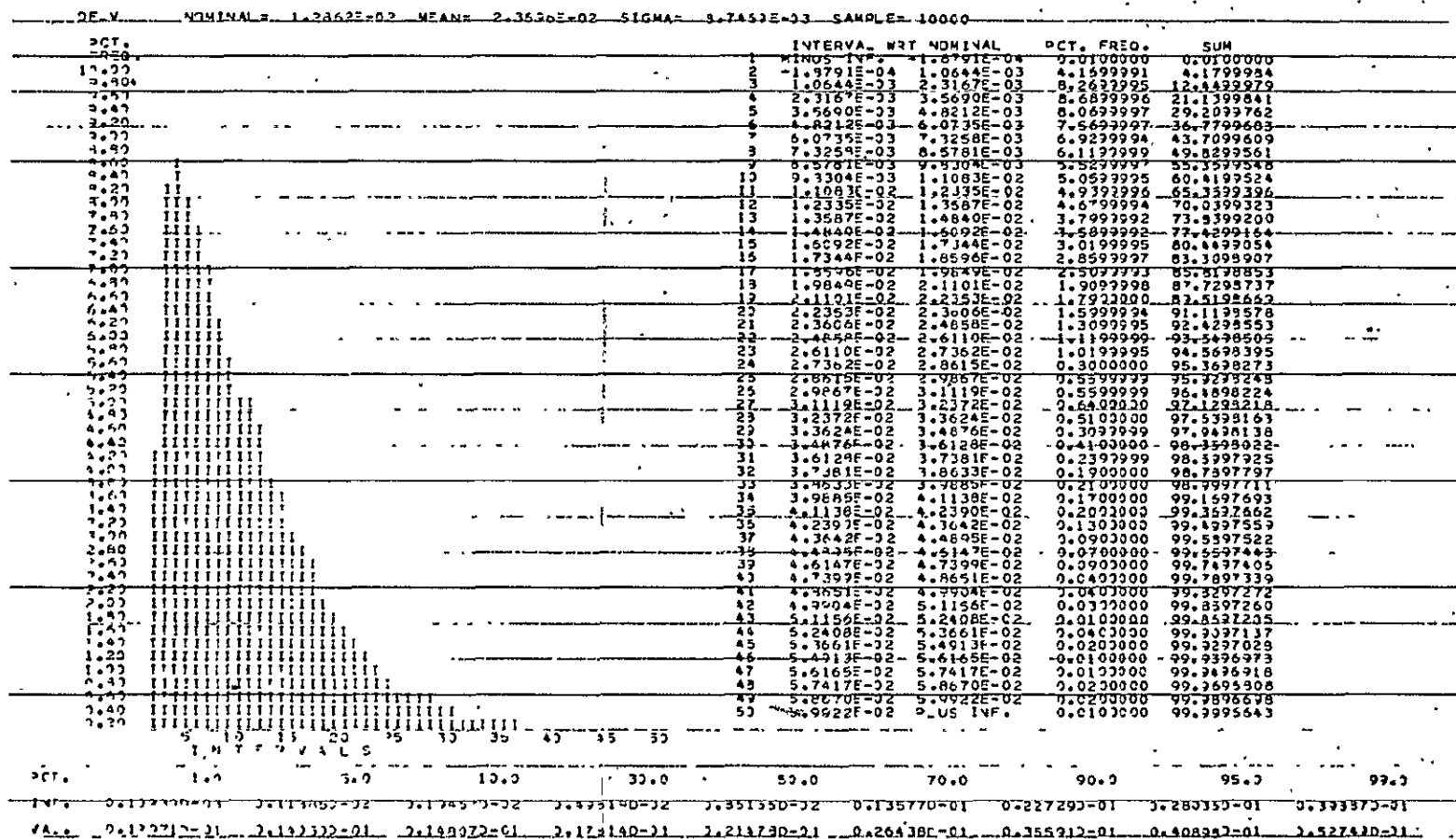


Figure A-9. Post-AMF Velocity To Acquire Station Histogram (Kilometers/Second)

A-11

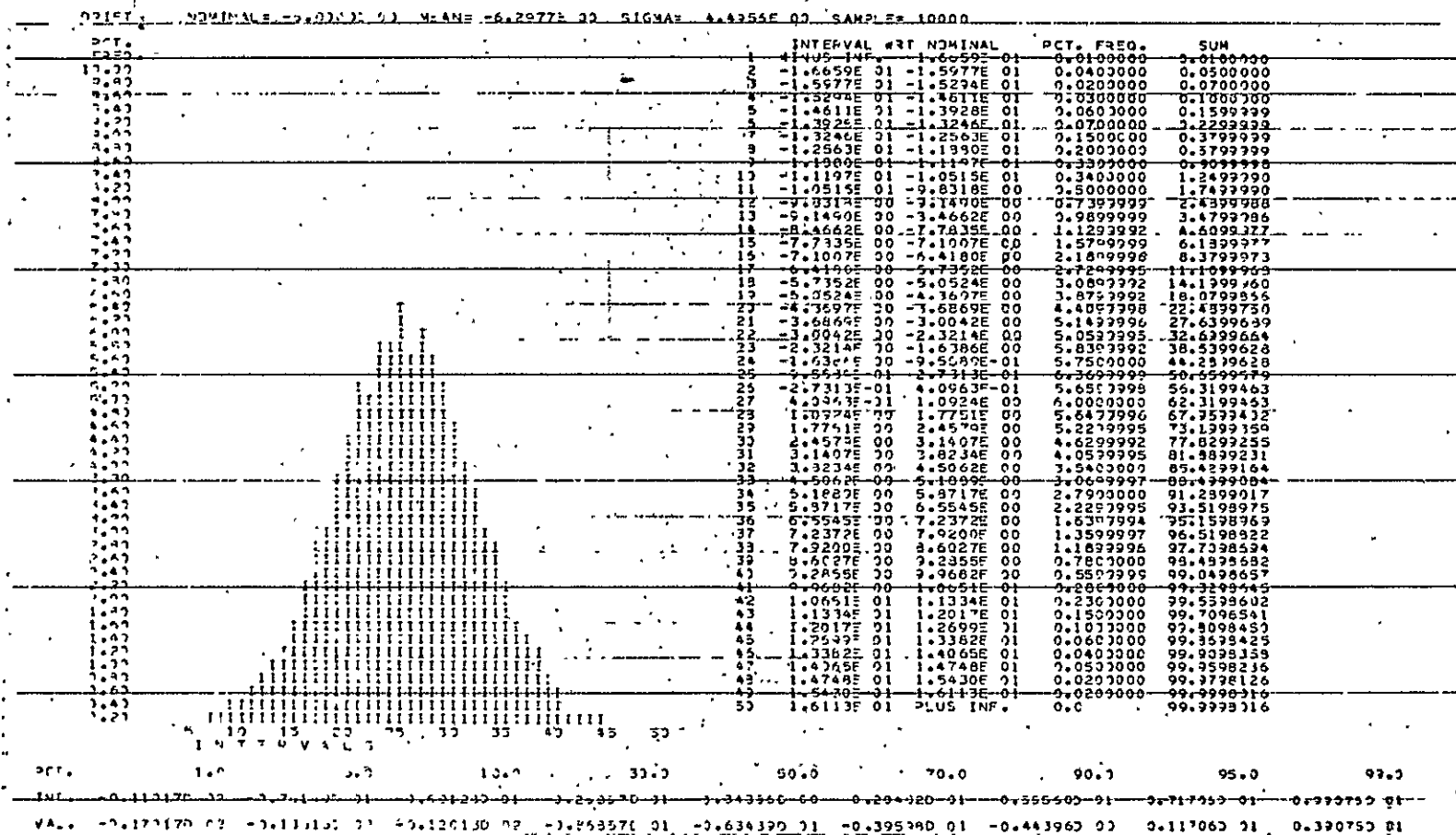


Figure A-10. Initial Longitudinal Drift Rate Histogram (Degrees/Day)

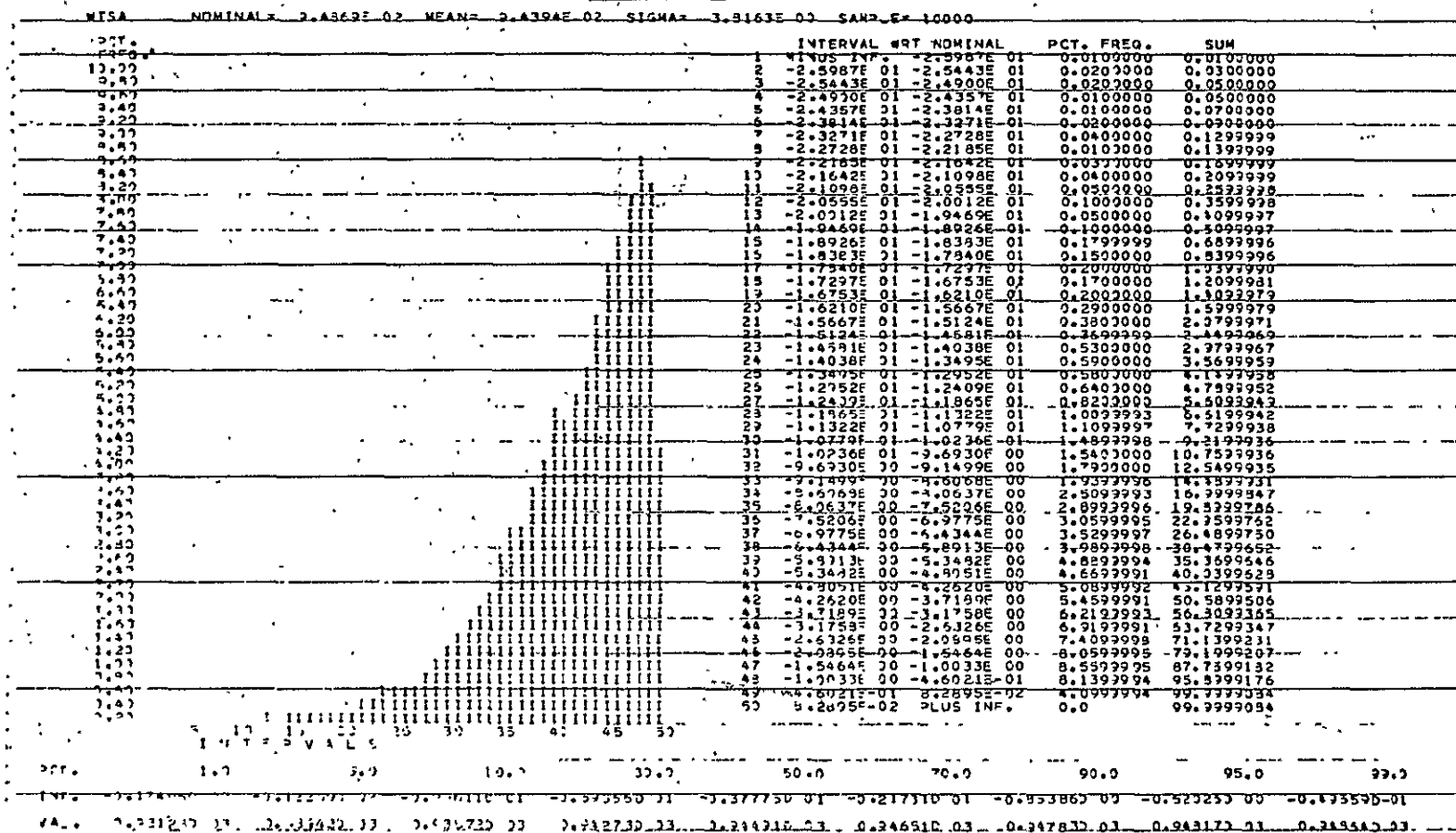


Figure A-11. On-Station Weight Histogram (Pounds)

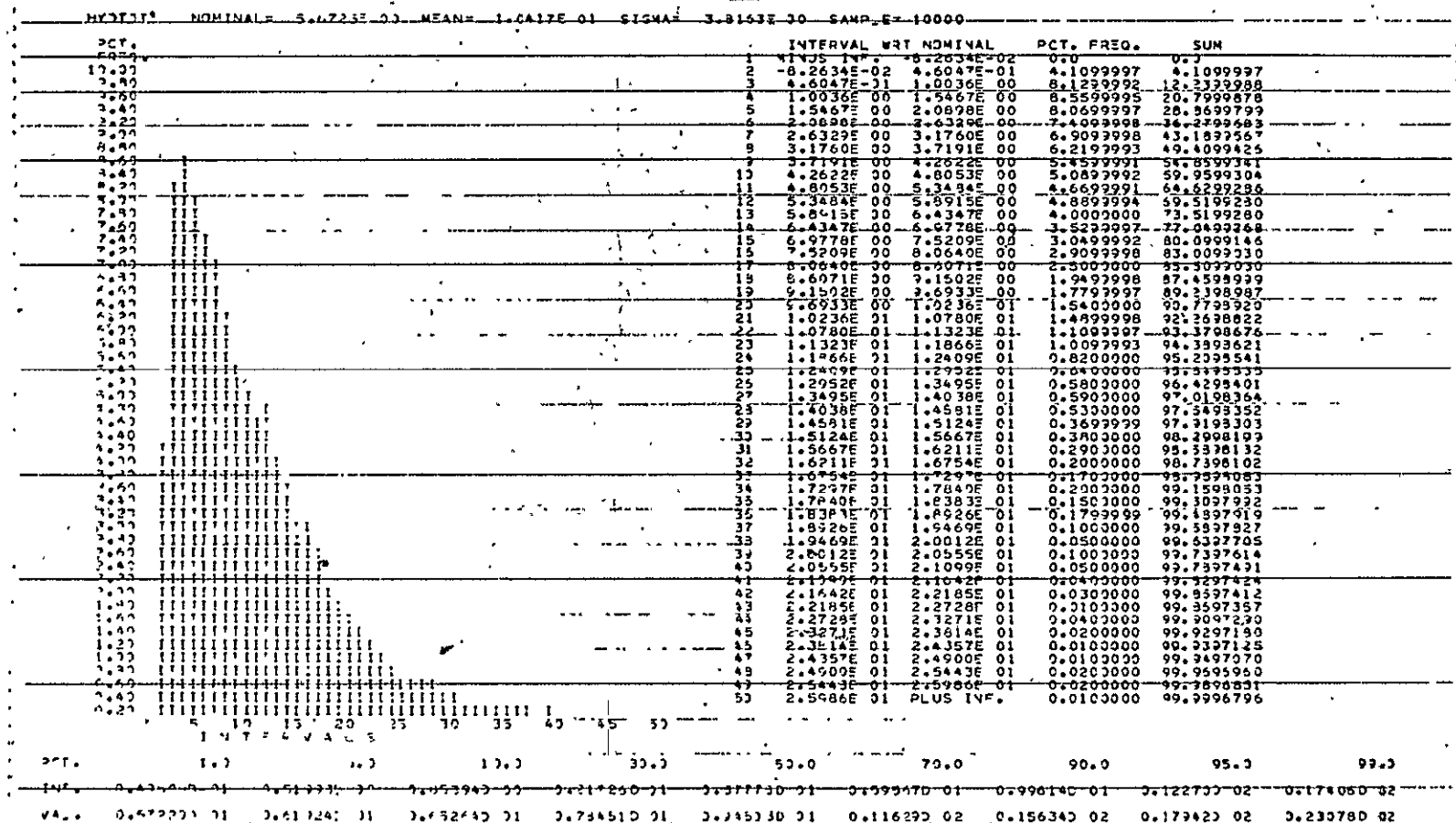


Figure A-12. Hydrazine Fuel Used To Acquire Station Histogram (Pounds)

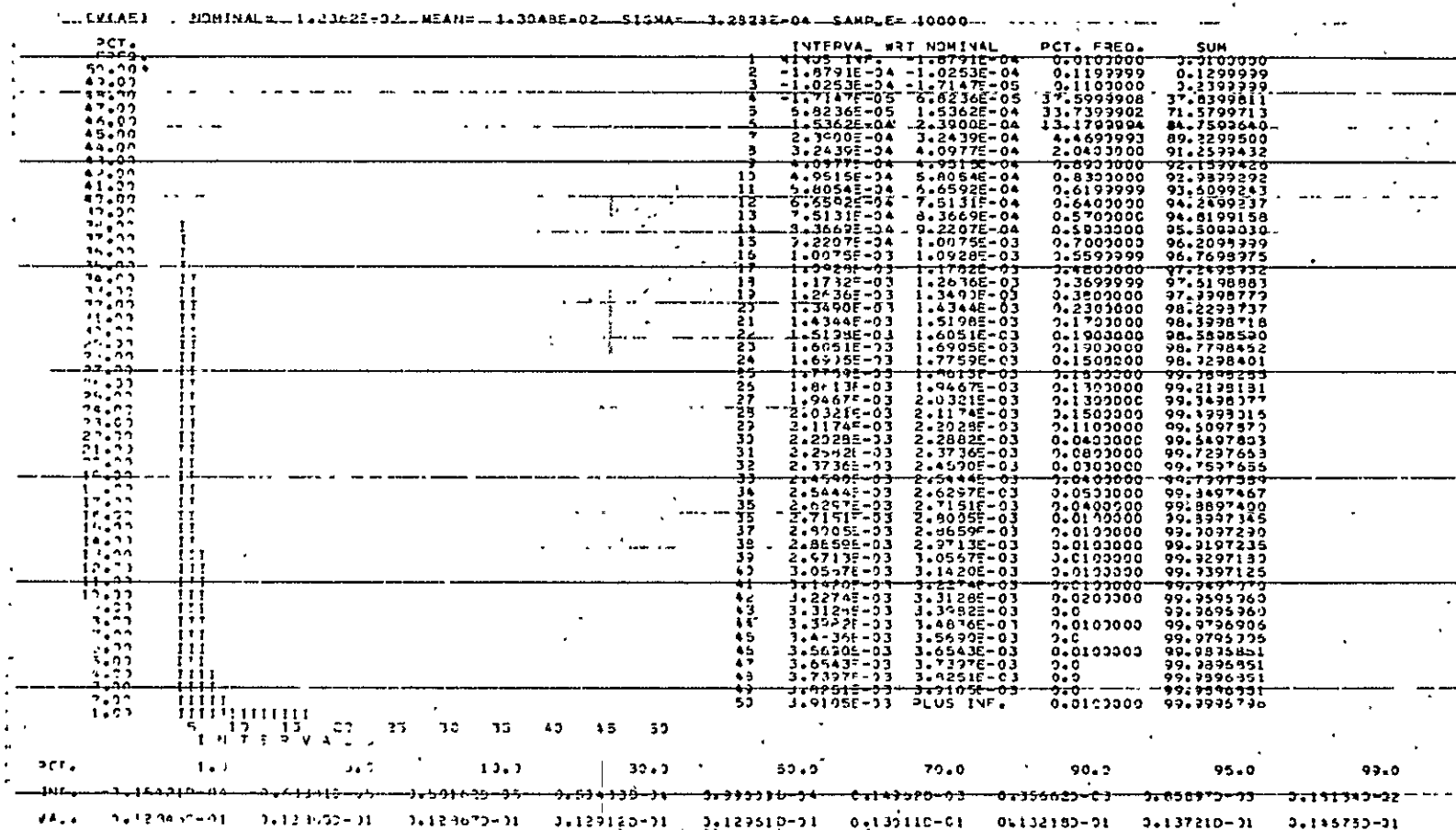


Figure A-13. Velocity Change Required To Correct Semimajor Axis and Eccentricity Histogram (Kilometers/Second)

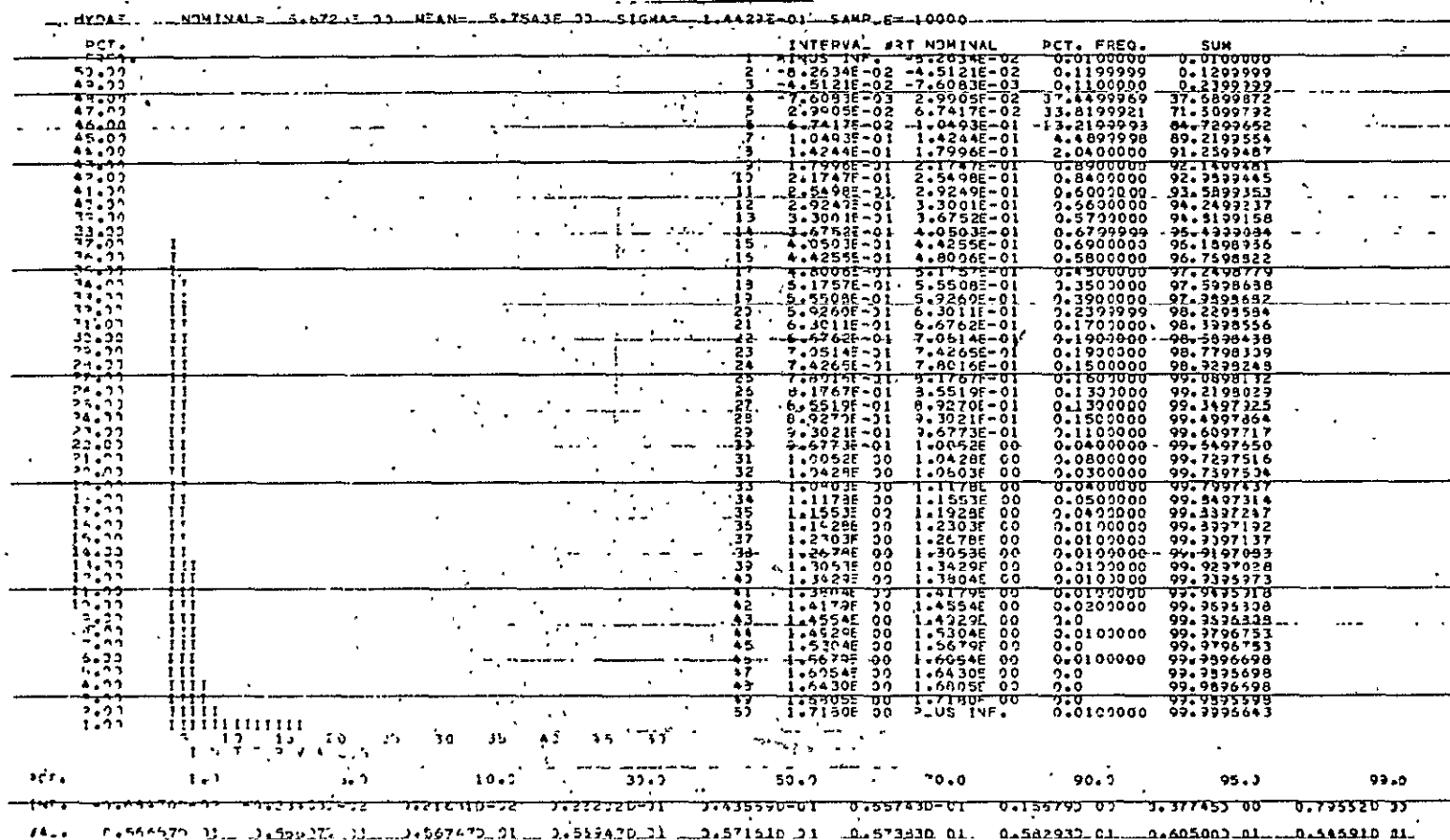


Figure A-14. Hydrazine Fuel Used To Correct Semimajor Axis and Eccentricity Histogram (Pounds)

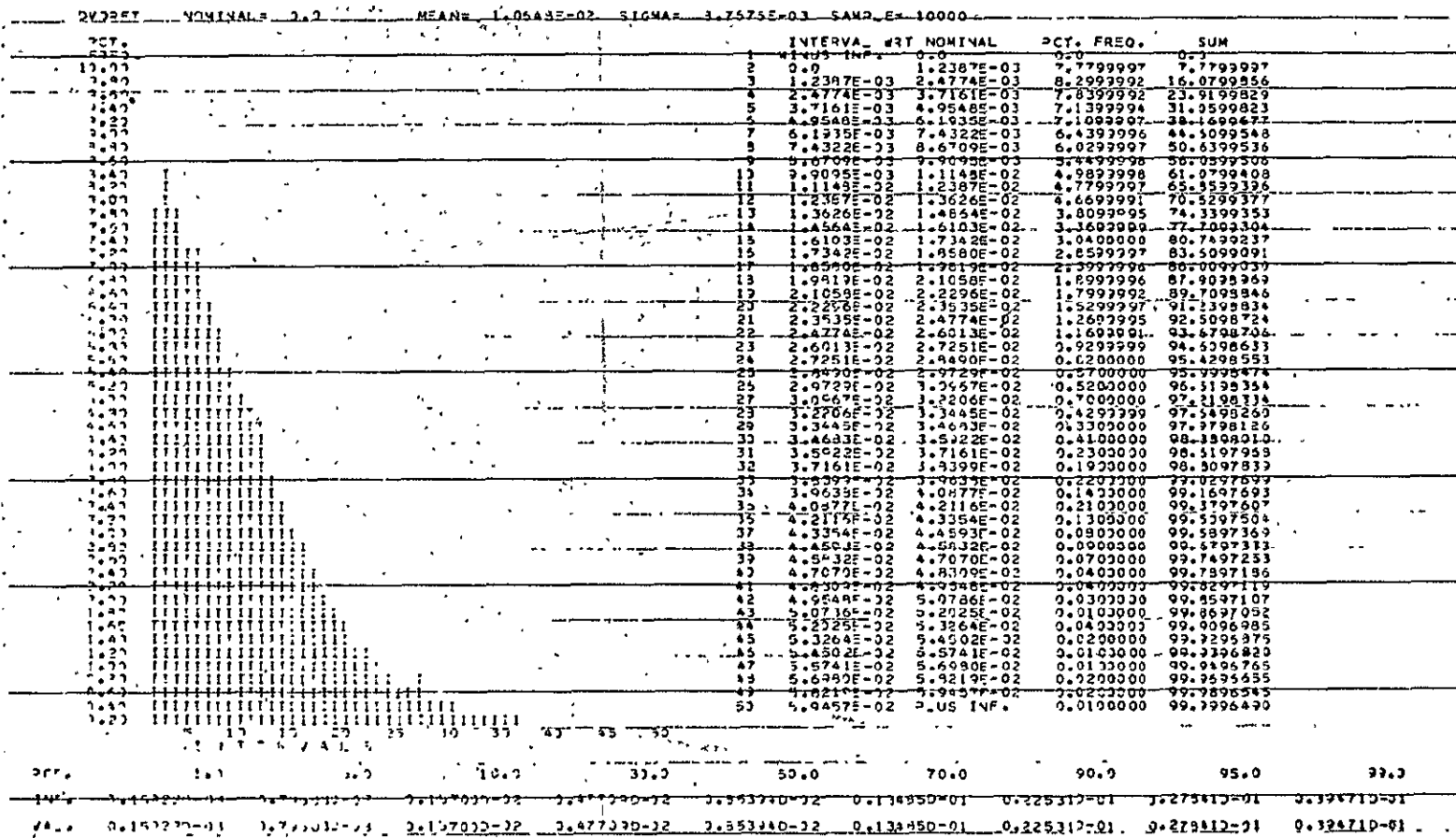
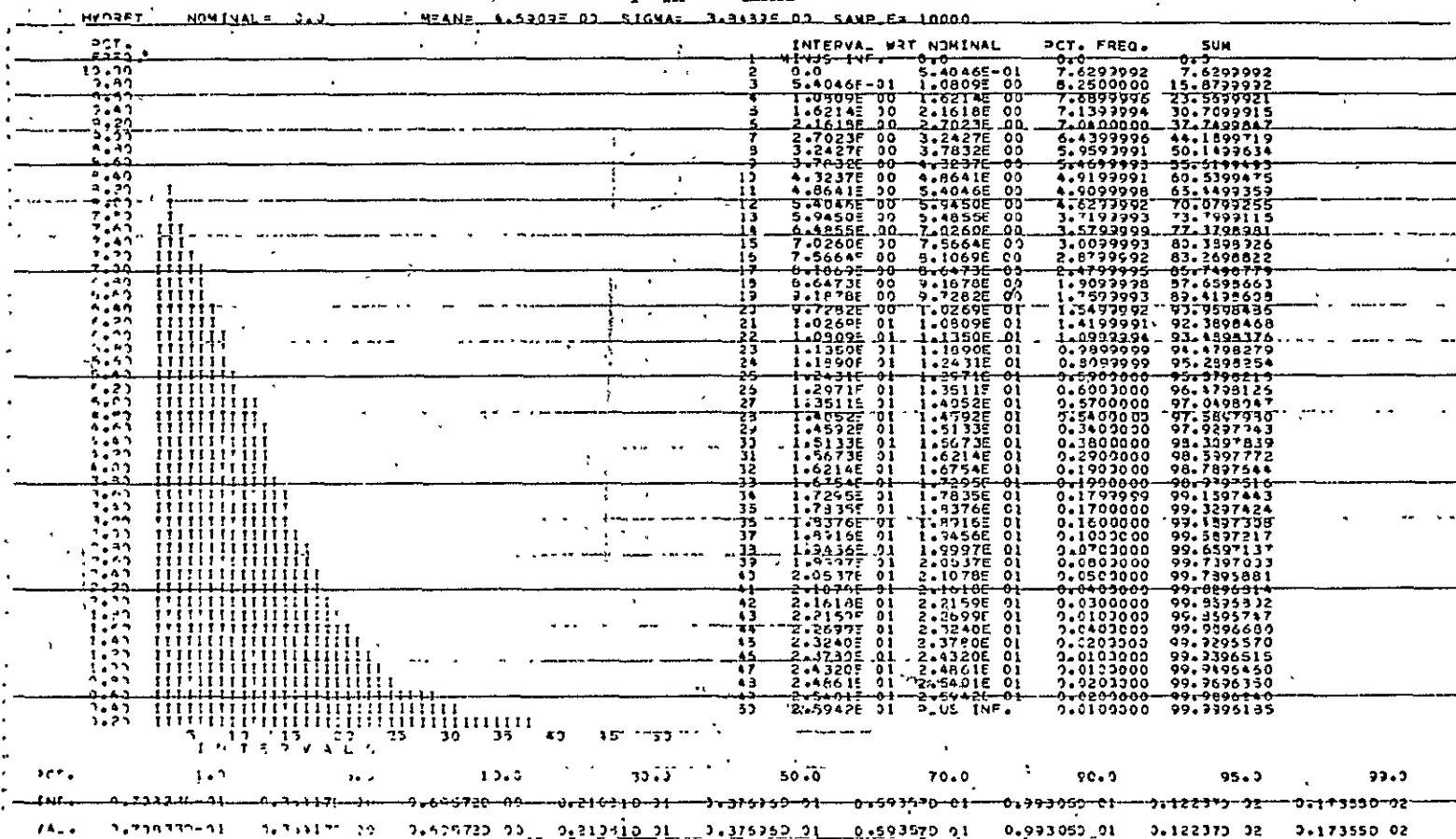


Figure A-15. Velocity Change Required to Correct Drift Rate Errors Histogram (Kilometers/Second)



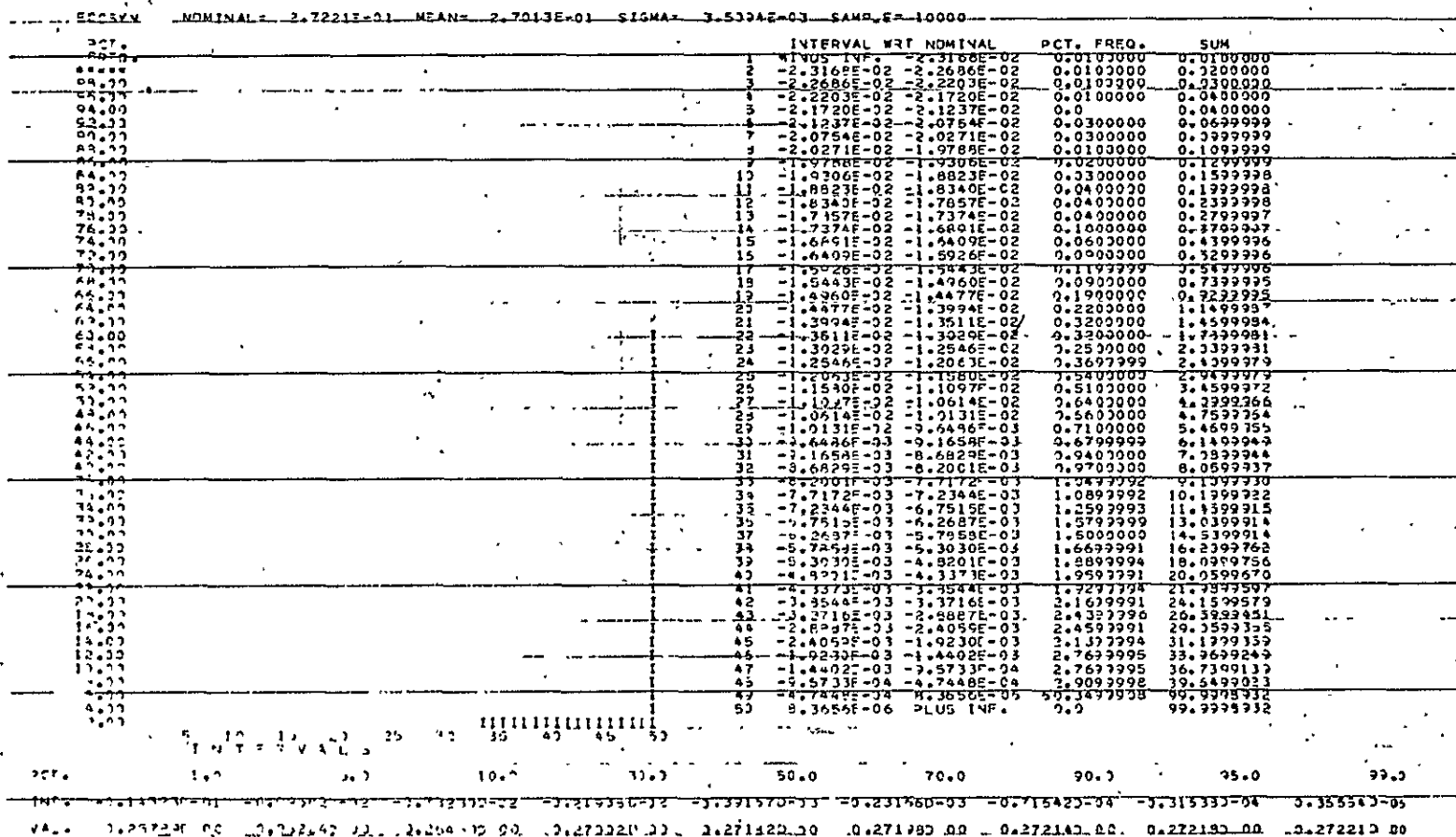


Figure A-17. Synchronous Orbit Eccentricity Histogram

APPENDIX B - SHADOW HISTORY CURVES

This appendix presents several plots of synchronous orbit shadow over a 5-year mission. For the node values used here, the 72-minute constraint is violated by both the umbra and penumbra shadow durations. Each figure is listed below:

1. Shadow History for 99th Percentile Low Argument of Perigee and a Node Angle 40 Degrees Below Nominal
2. Shadow History for 99th Percentile Low Argument of Perigee and a Node Angle 50 Degrees Above Nominal
3. Shadow History for 99th Percentile High Argument of Perigee and a Node Angle 40 Degrees Below Nominal
4. Shadow History for 99th Percentile High Argument of Perigee and a Node Angle 50 Degrees Above Nominal

THE SHADOW HISTORY
 NODE-180 AOP-228

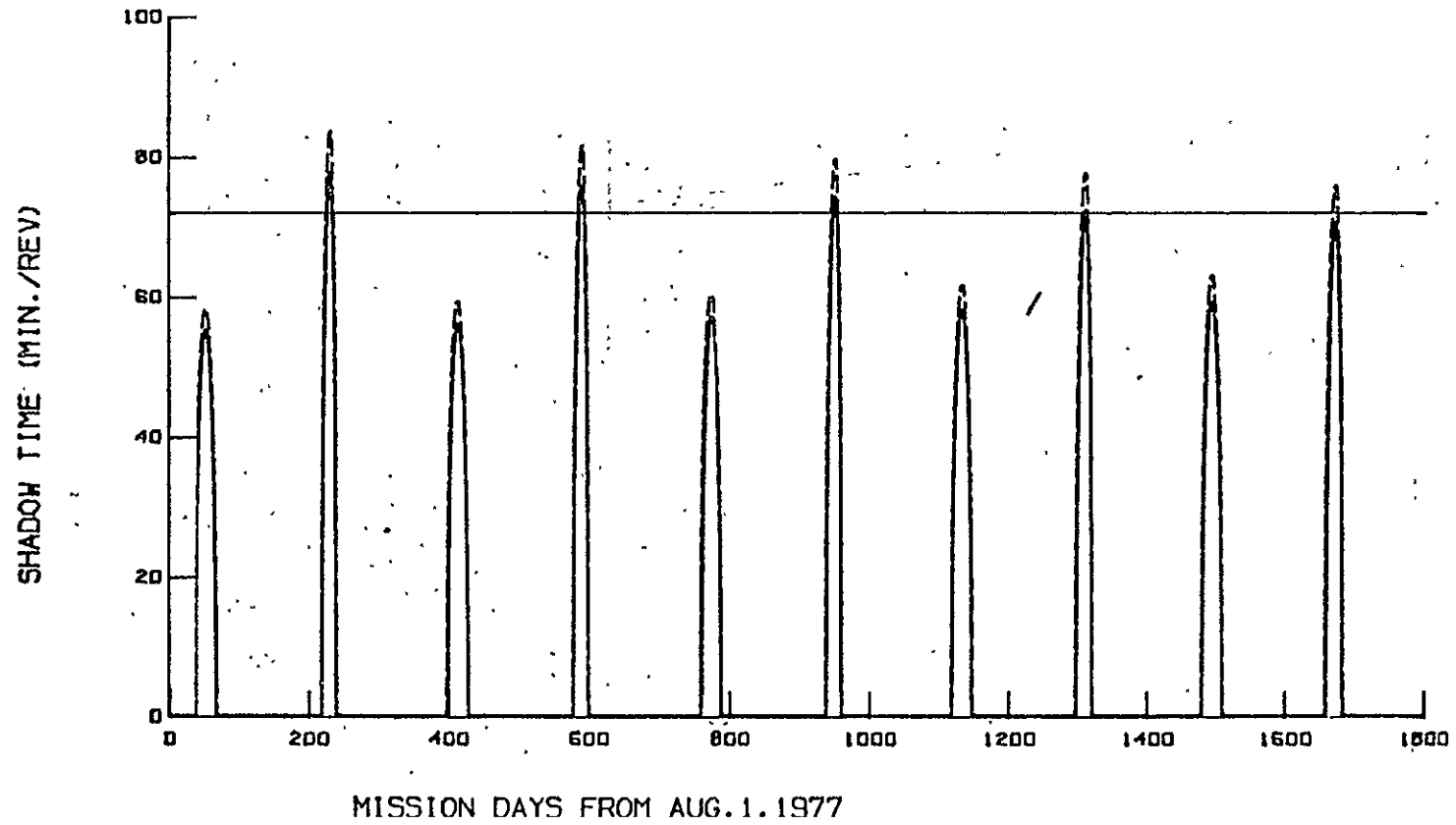


Figure B-1. Shadow History for 99th Percentile Low Argument of Perigee and a Node Angle 40 Degrees Below Nominal

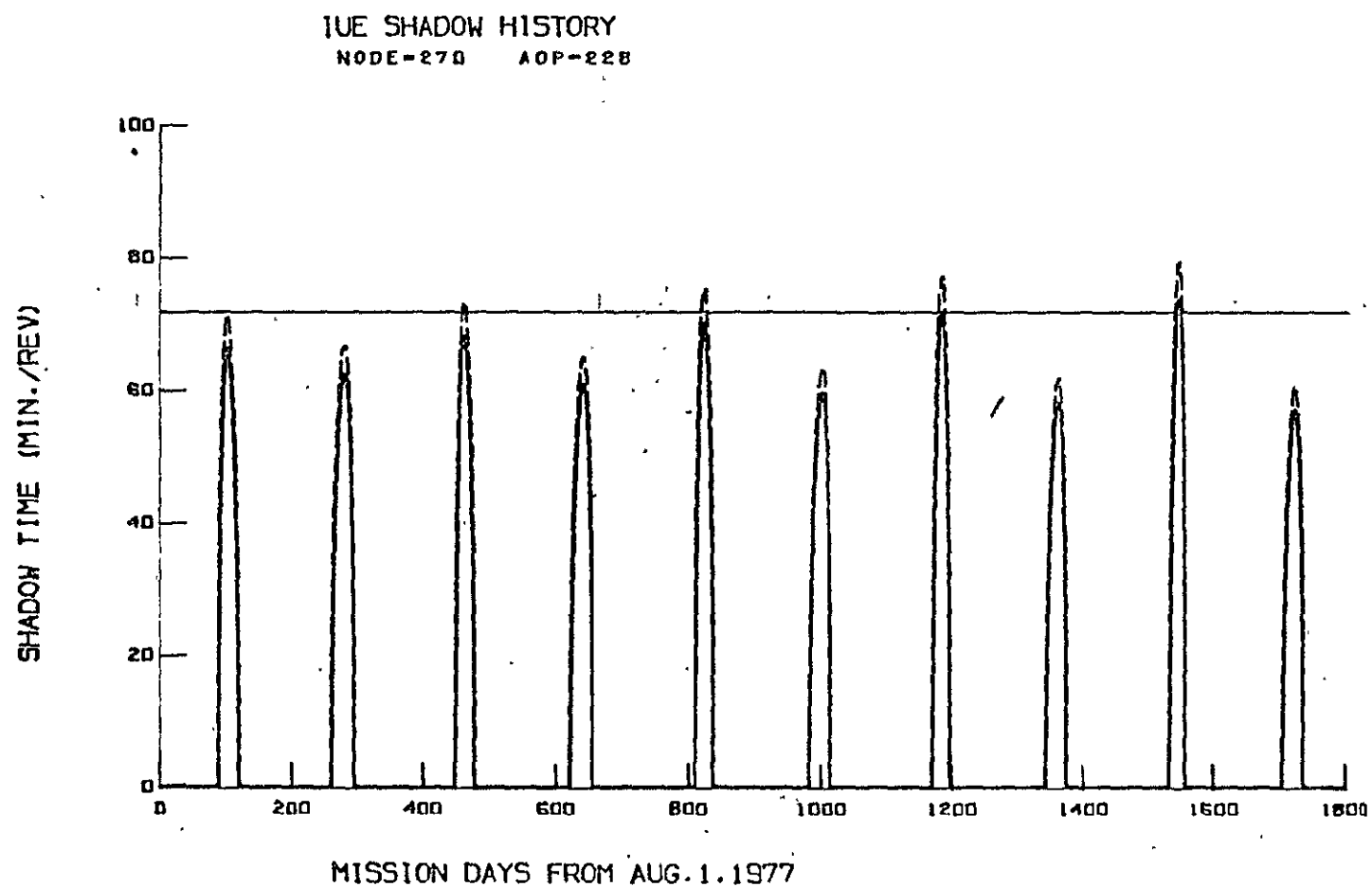


Figure B-2. Shadow History for 99th Percentile Low Argument of Perigee and a Node Angle 50 Degrees Above Nominal

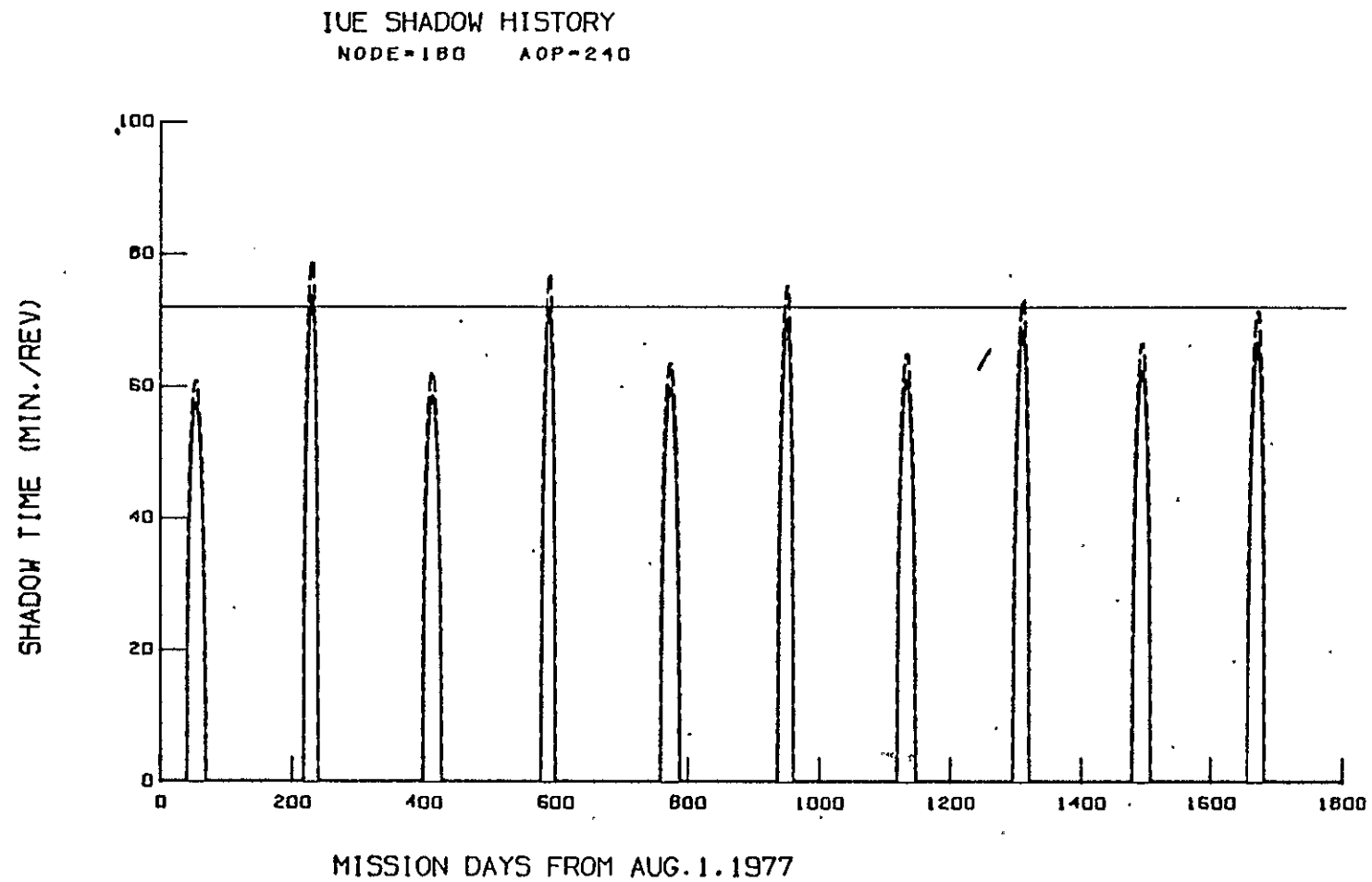


Figure B-3. Shadow History for 99th Percentile High Argument of Perigee and a Node Angle 40 Degrees Below Nominal

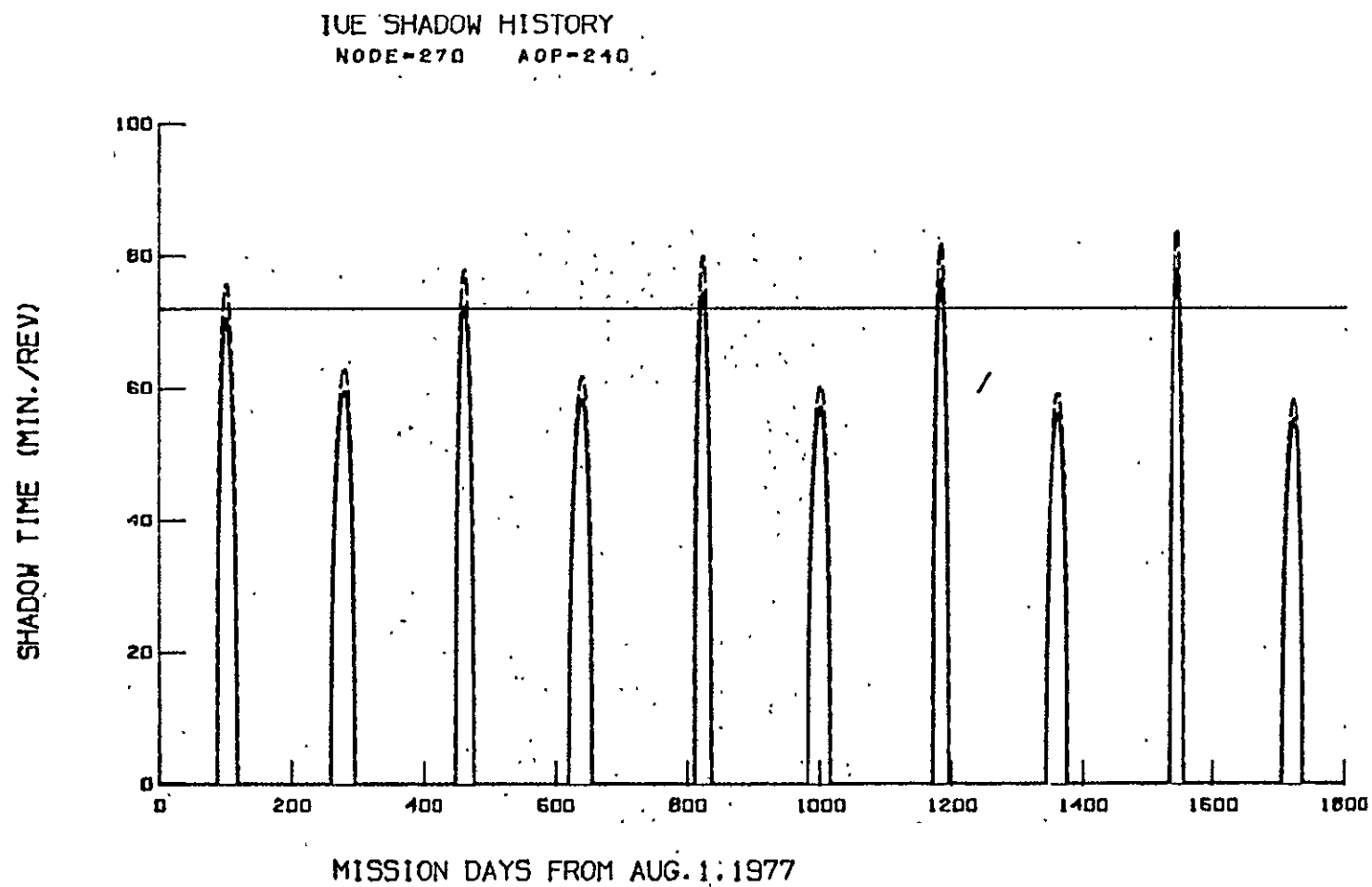


Figure B-4. Shadow History for 99th Percentile High Argument of Perigee and a Node Angle 50 Degrees Above Nominal

APPENDIX C - TRACKING COVERAGE

This appendix presents tracking coverage for five apogee passages in the transfer orbit and for each phase of the drift orbit up to station acquisition. For all tracking sites, except GSFC and VILFRA, a constant 5-degree elevation mask was assumed. For GSFC, the mask for the NTTF 12-meter antenna (STDN no. 705) was used. Two masks were used for the VILFRA tracking site. In the following figures, the label VILFRA means the physical mask was used; the label VIL+10 means the physical mask plus 10 degrees was used. The list of figures follows:

1. Tracking Coverage for First Apogee in Transfer Orbit
2. Tracking Coverage for Second Apogee in Transfer Orbit
3. Tracking Coverage for Third Apogee in Transfer Orbit
4. Tracking Coverage for Fourth Apogee in Transfer Orbit
5. Tracking Coverage for Fifth Apogee in Transfer Orbit
6. Tracking Coverage for Drift Orbit Phase 1
7. Tracking Coverage for Drift Orbit Phase 2
8. Tracking Coverage for Drift Orbit Phase 3
9. Tracking Coverage for First Day of Synchronous Orbit

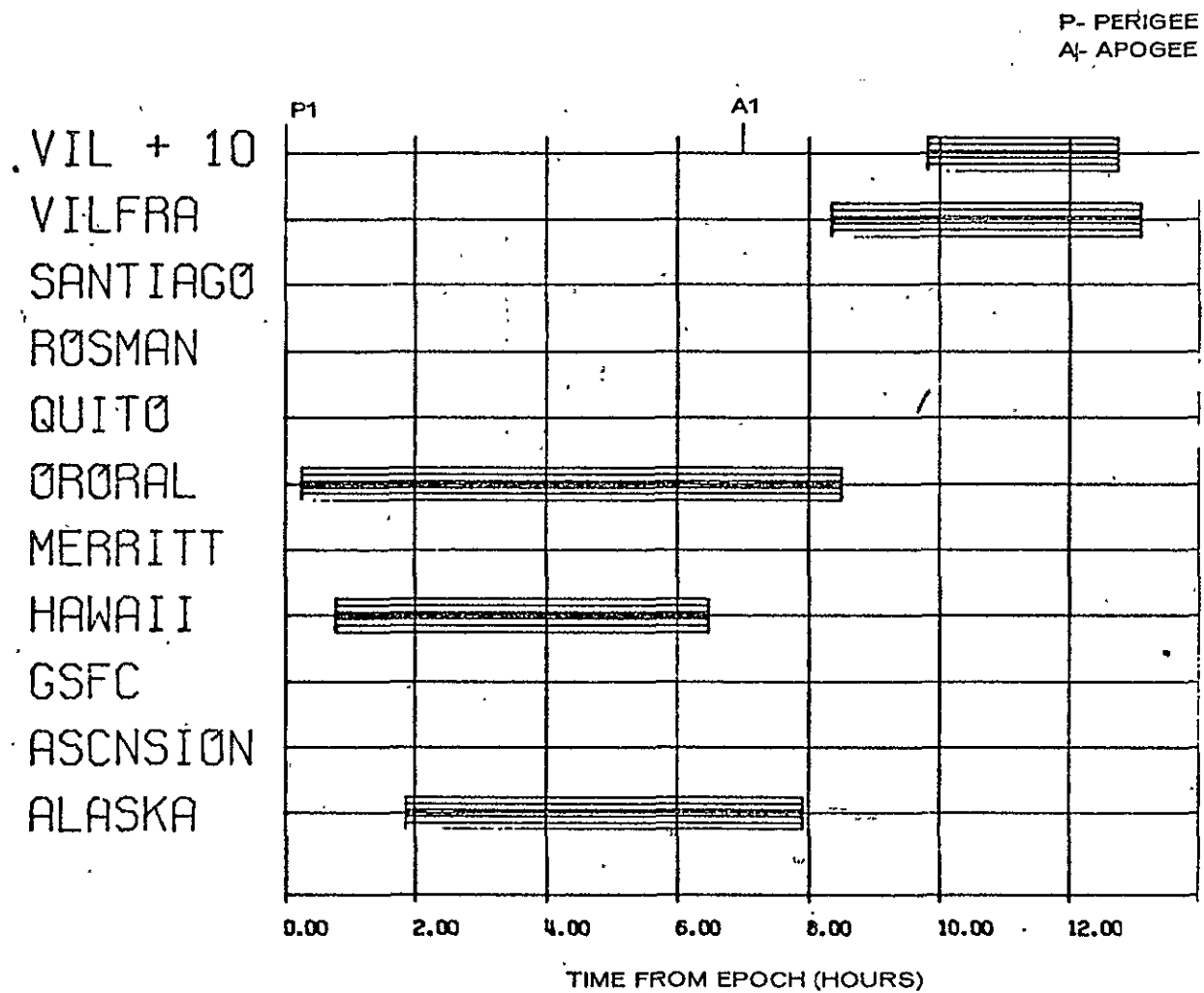


Figure C-1. Tracking Coverage for First Apogee in Transfer Orbit

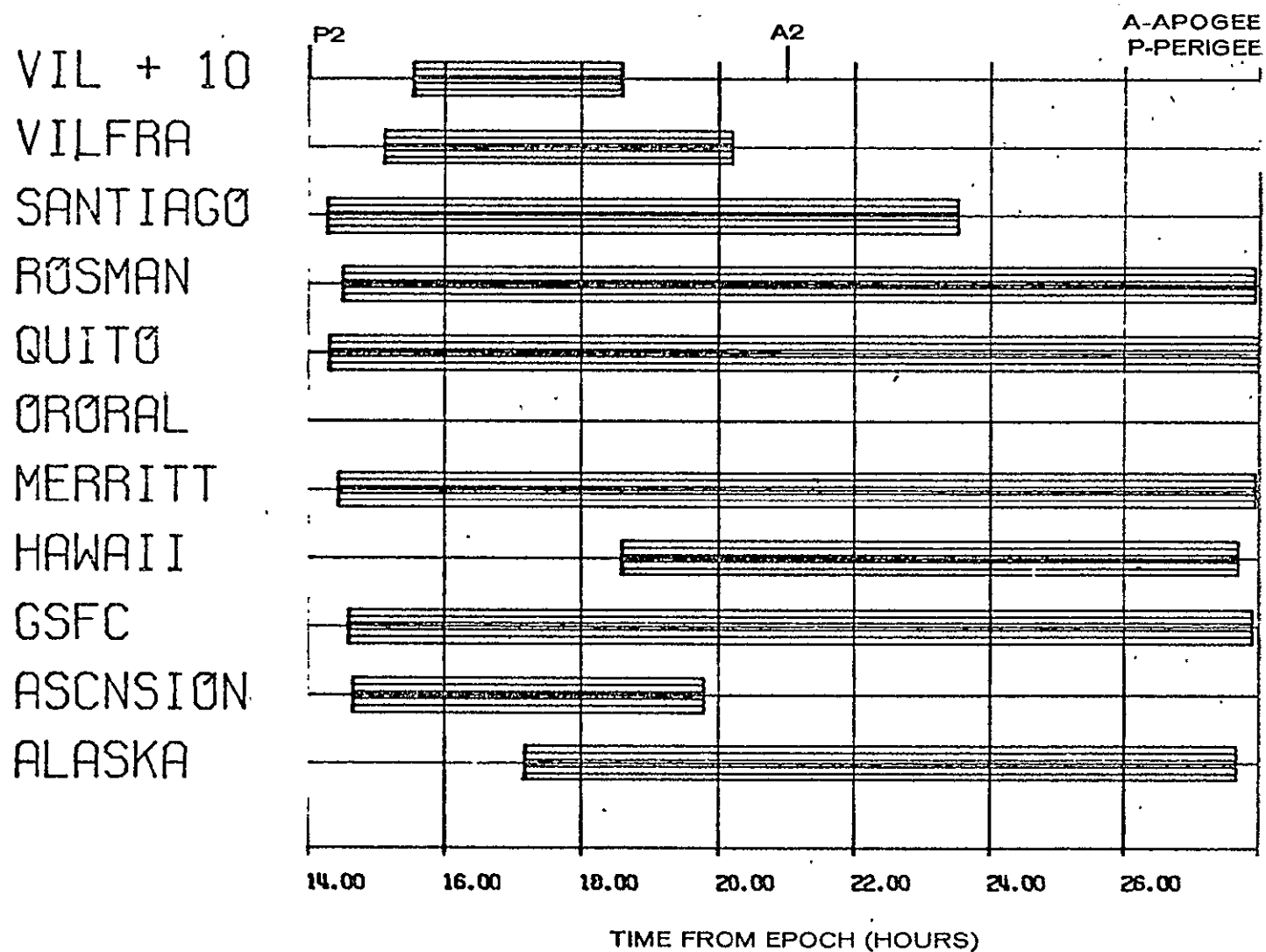


Figure C-2. Tracking Coverage for Second Apogee in Transfer Orbit

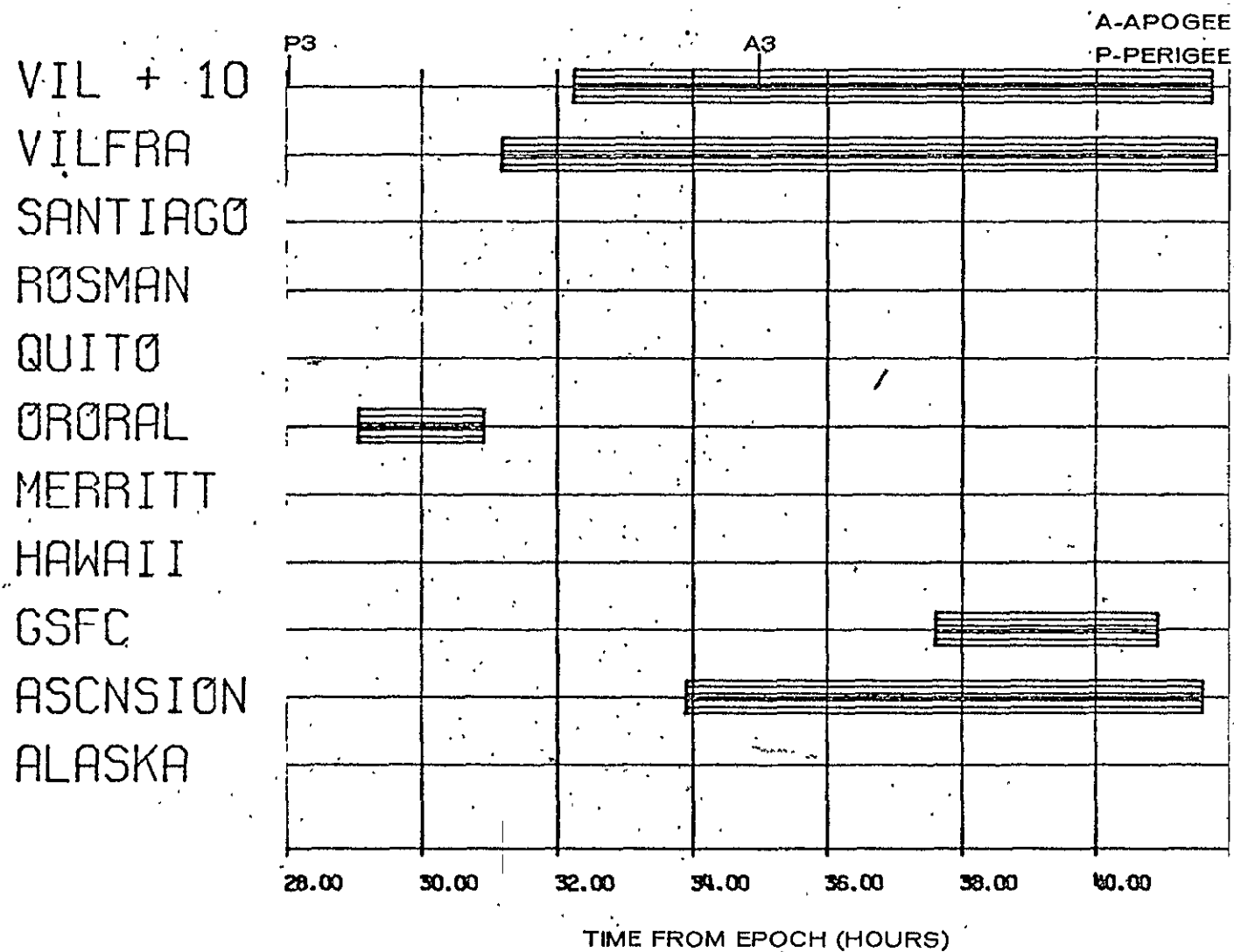


Figure C-3. Tracking Coverage for Third Apogee in Transfer Orbit

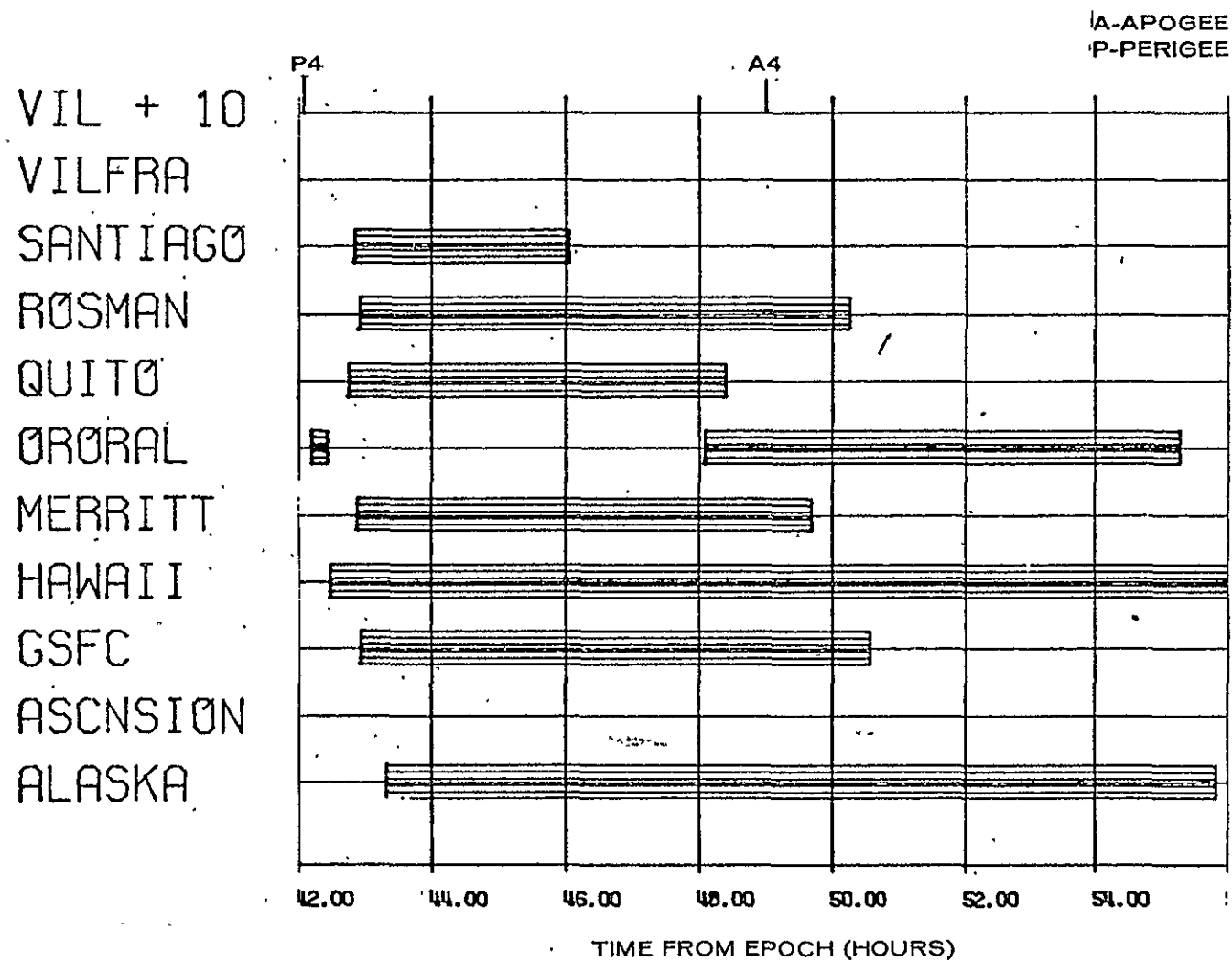


Figure C-4. Tracking Coverage for Fourth Apogee in Transfer Orbit

C-6

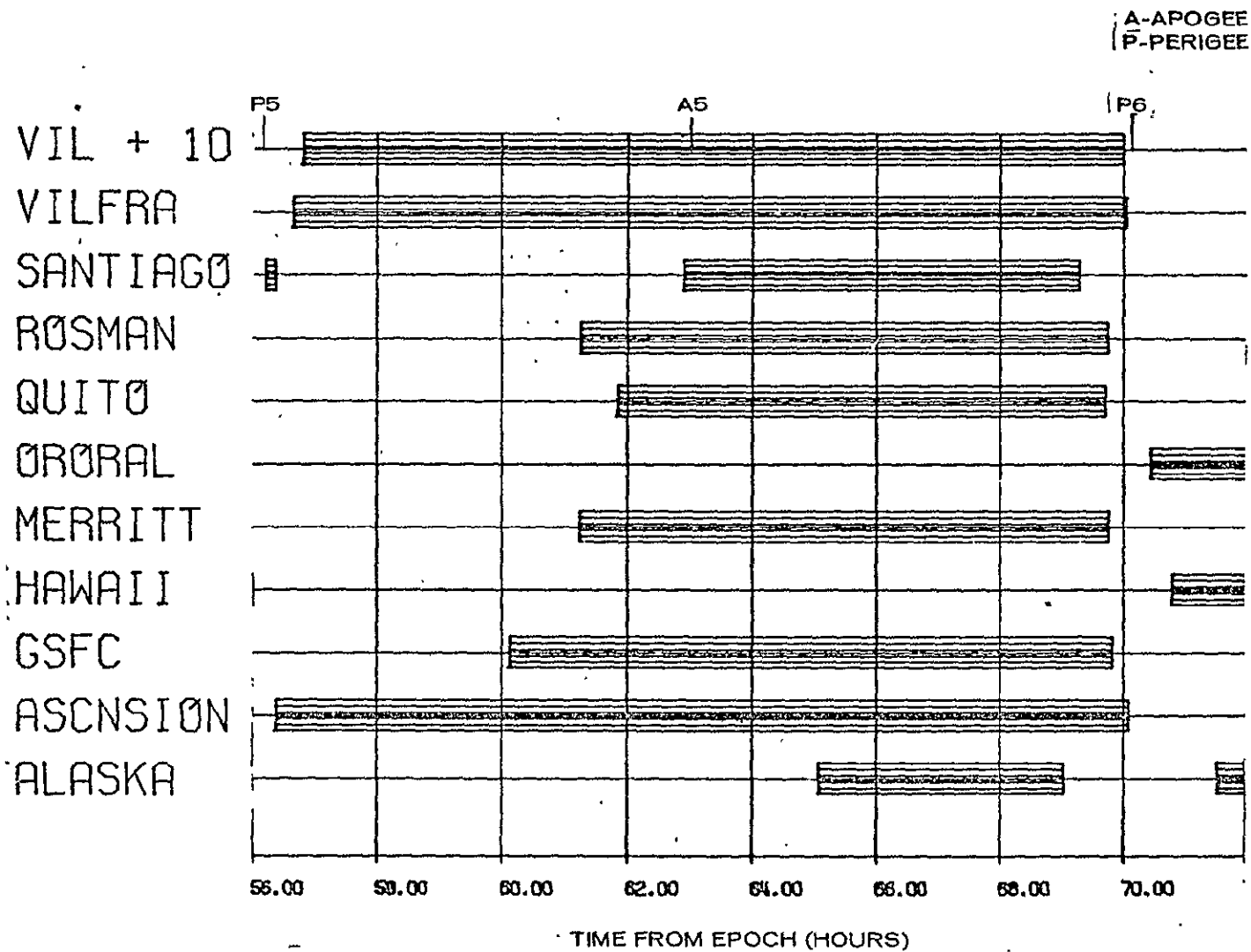


Figure C-5. Tracking Coverage for Fifth Apogee in Transfer Orbit

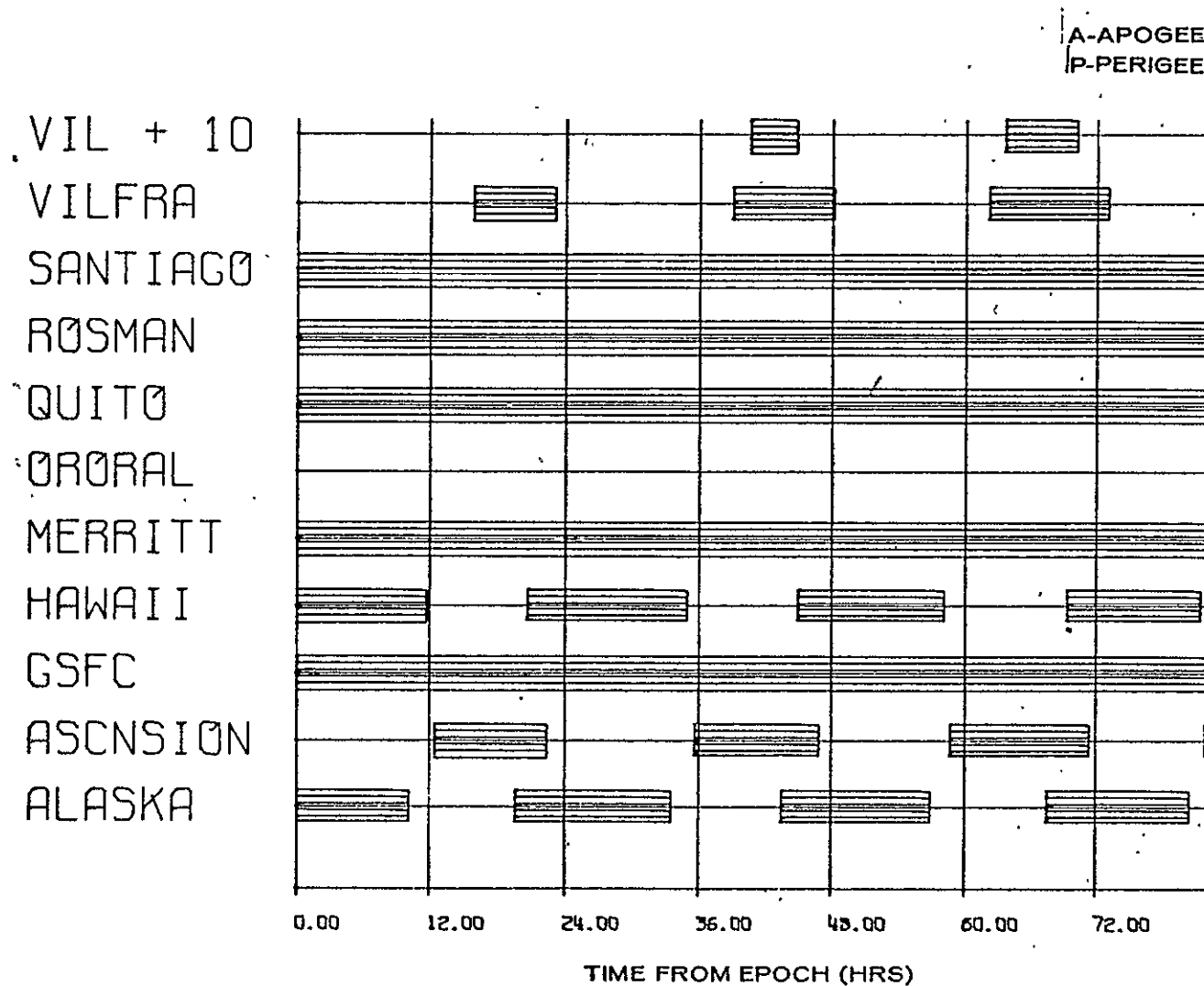


Figure C-6. Tracking Coverage for Drift Orbit Phase 1

A-APOGEE
P-PERIGEE

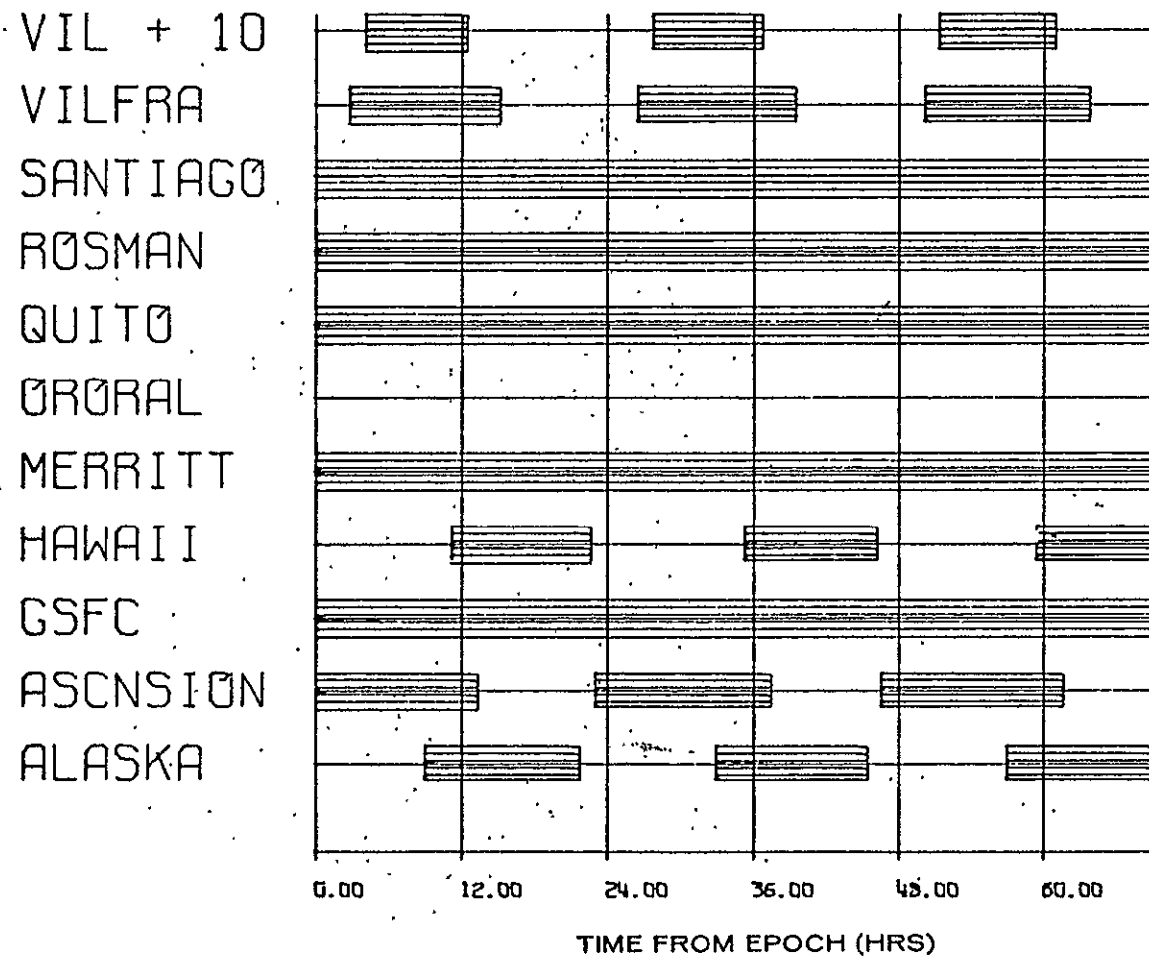


Figure C-7. Tracking Coverage for Drift Orbit Phase 2

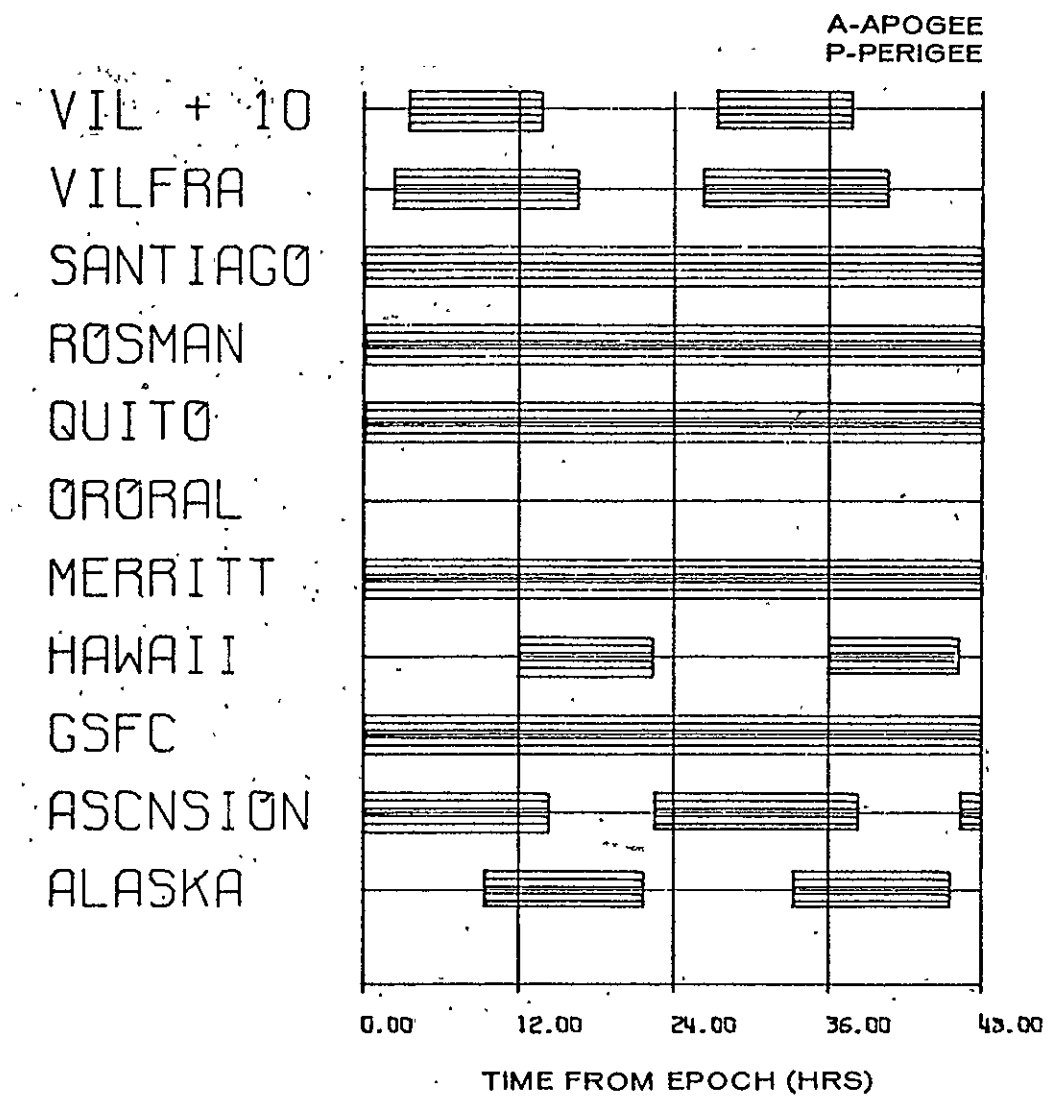


Figure C-8. Tracking Coverage for Drift Orbit Phase 3

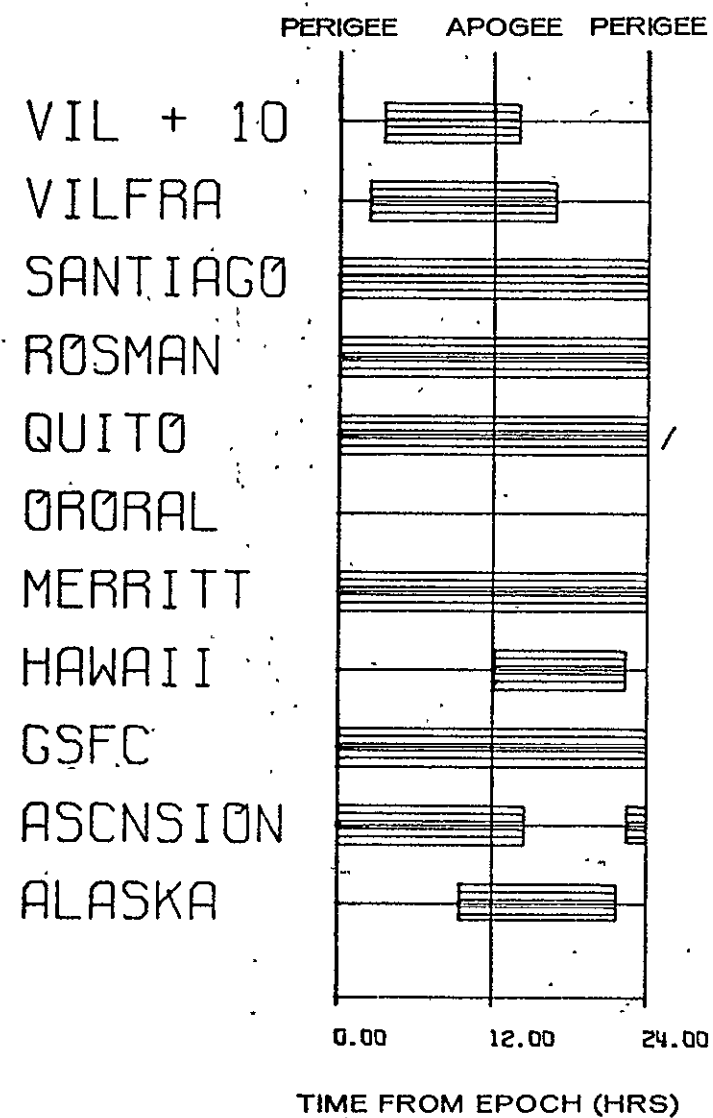


Figure C-9. Tracking Coverage for First Day of Synchronous Orbit

APPENDIX D - LAUNCH WINDOW CONSTRAINT PARAMETER CONTOUR PLOTS

This appendix presents contour plots of the individual constraint parameters used in defining the launch window. Each figure is plotted in terms of parking orbit node and launch date. Contour angles are in degrees. The figures are

1. Transfer Shadow Contours
2. Contours of Solar Aspect Angle at Third-Stage Ignition
(Transfer Orbit Injection)
3. Contours of Solar Aspect Angle at Fourth-Stage Ignition
(Apogee Boost Motor)
4. Contours of Minimum Separation Angle During 3 Hours
Prior to Apogee
5. Contours of Maximum Separation Angle During 3 Hours
Prior to Apogee

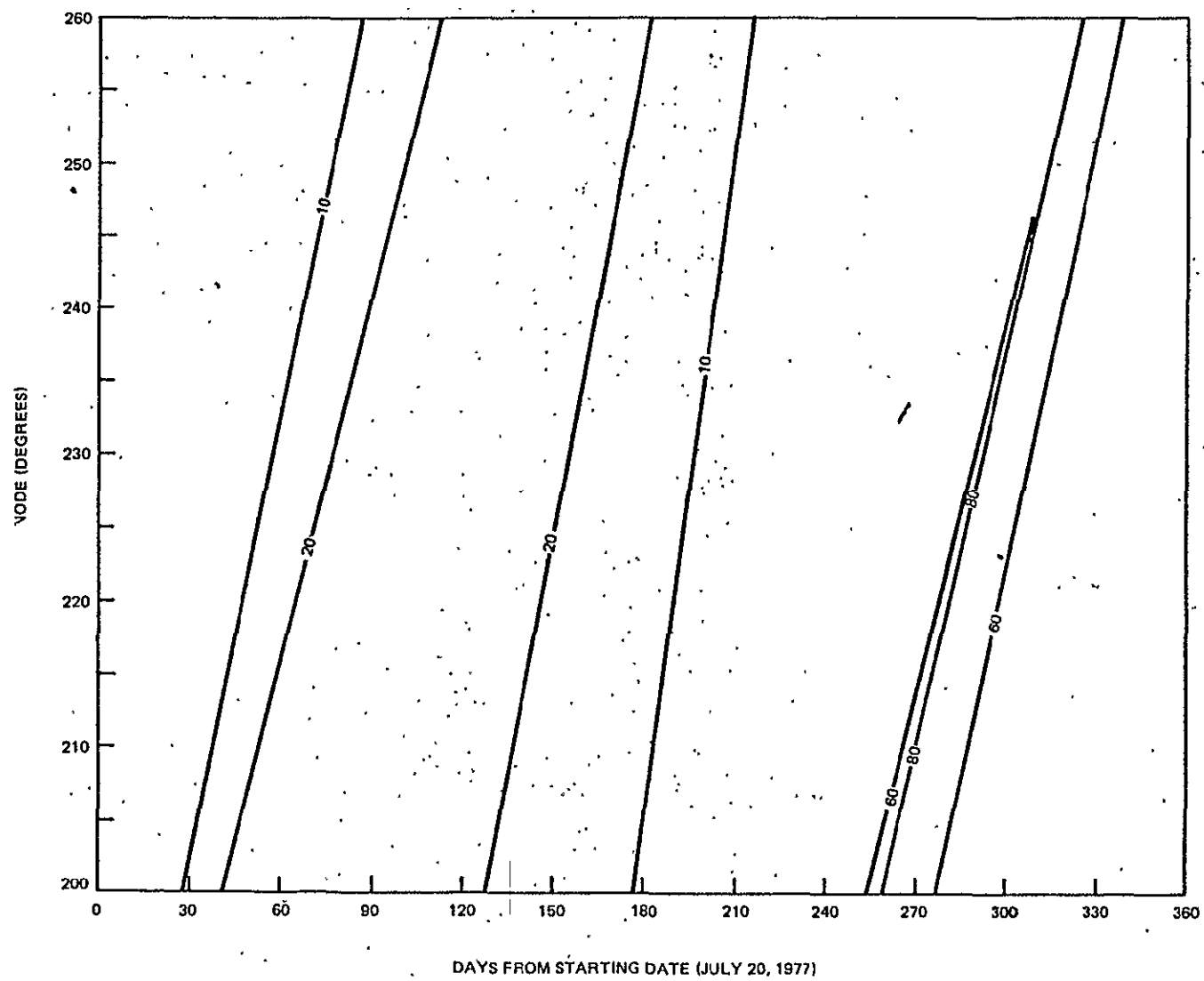


Figure D-1. Transfer Shadow Contours (Minutes)

D-3

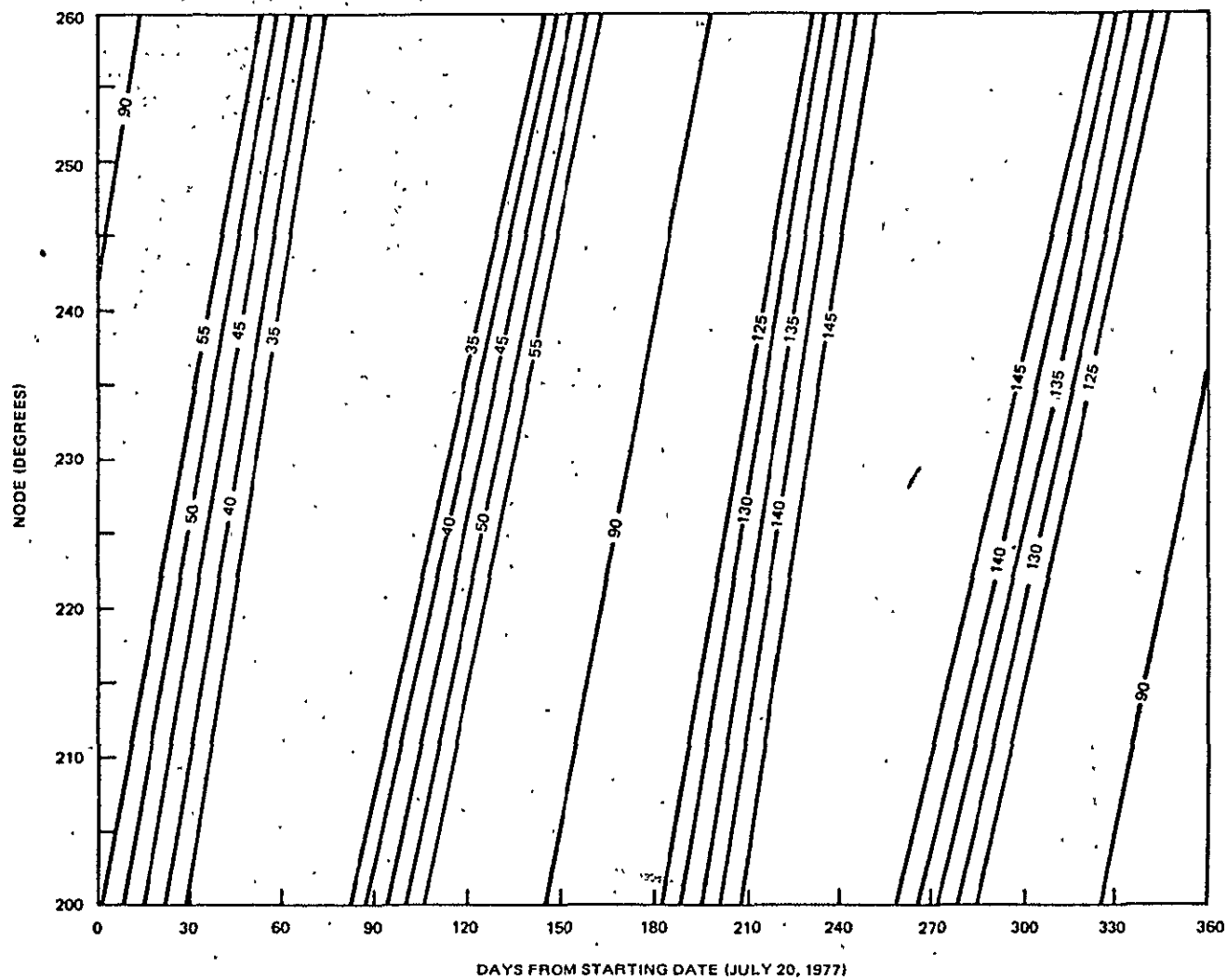


Figure D-2. Contours of Solar Aspect Angle at Third-Stage Ignition (Transfer Orbit Injection)

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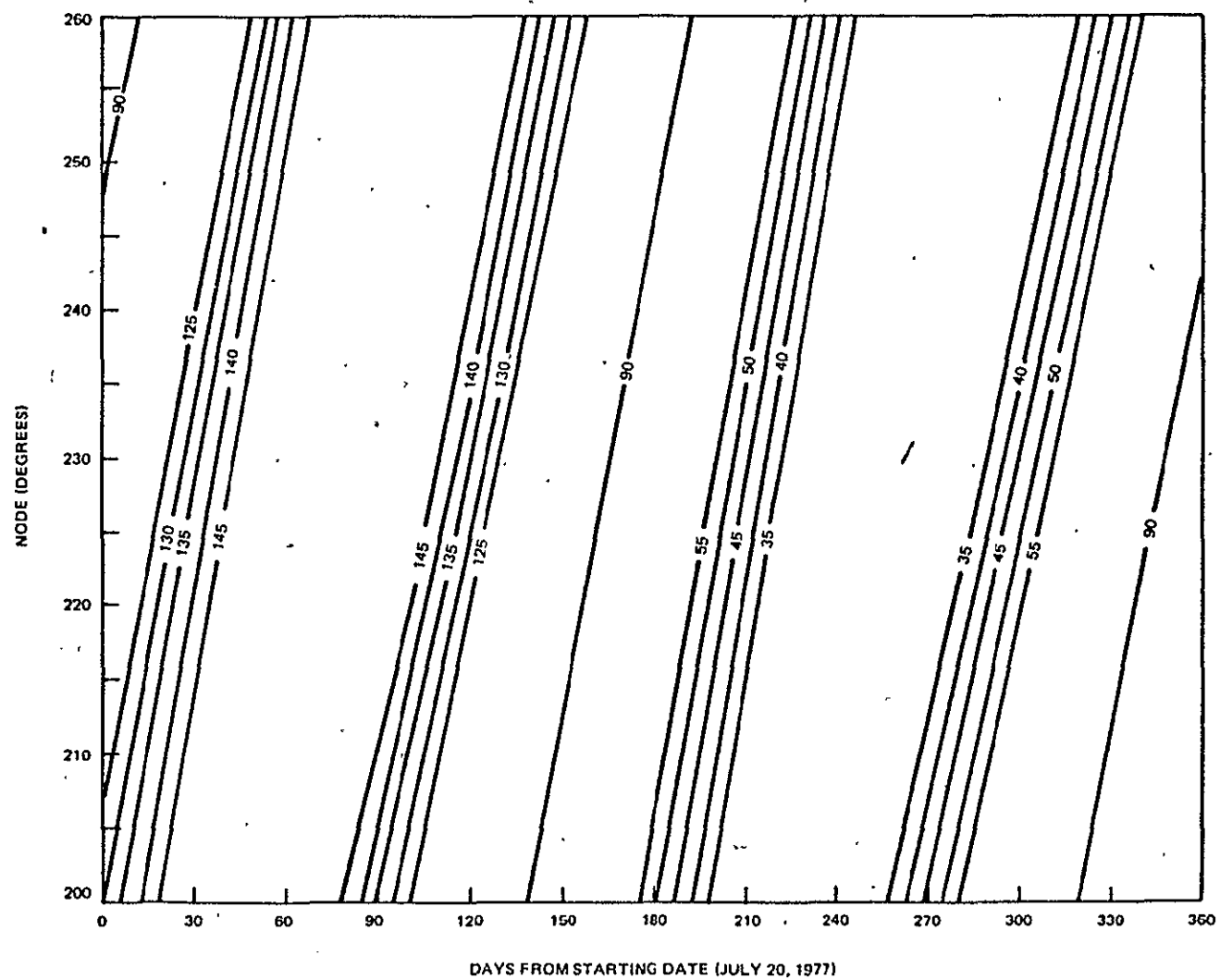


Figure D-3. Contours of Solar Aspect Angle at Fourth-Stage Ignition (Apogee Boost Motor)

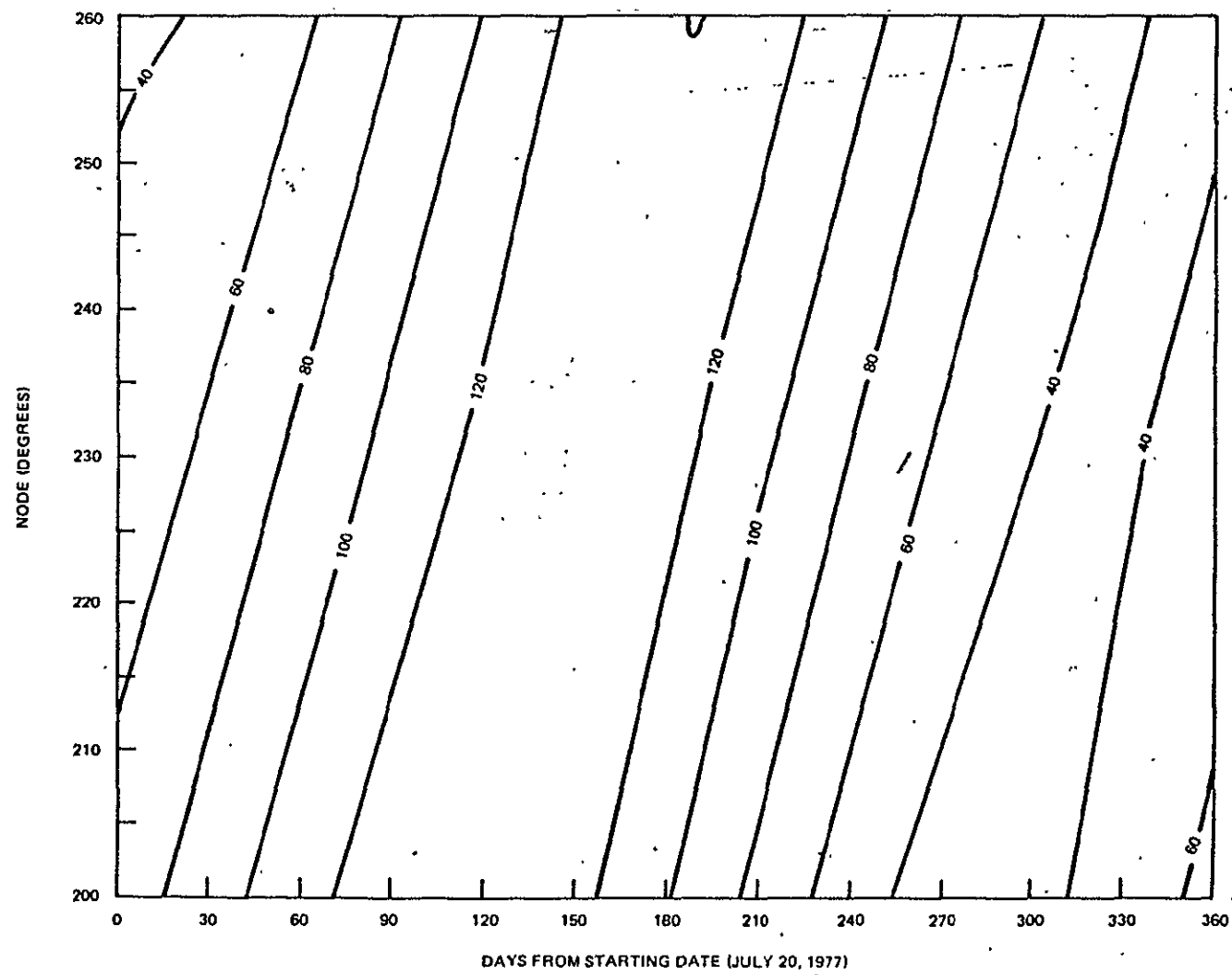
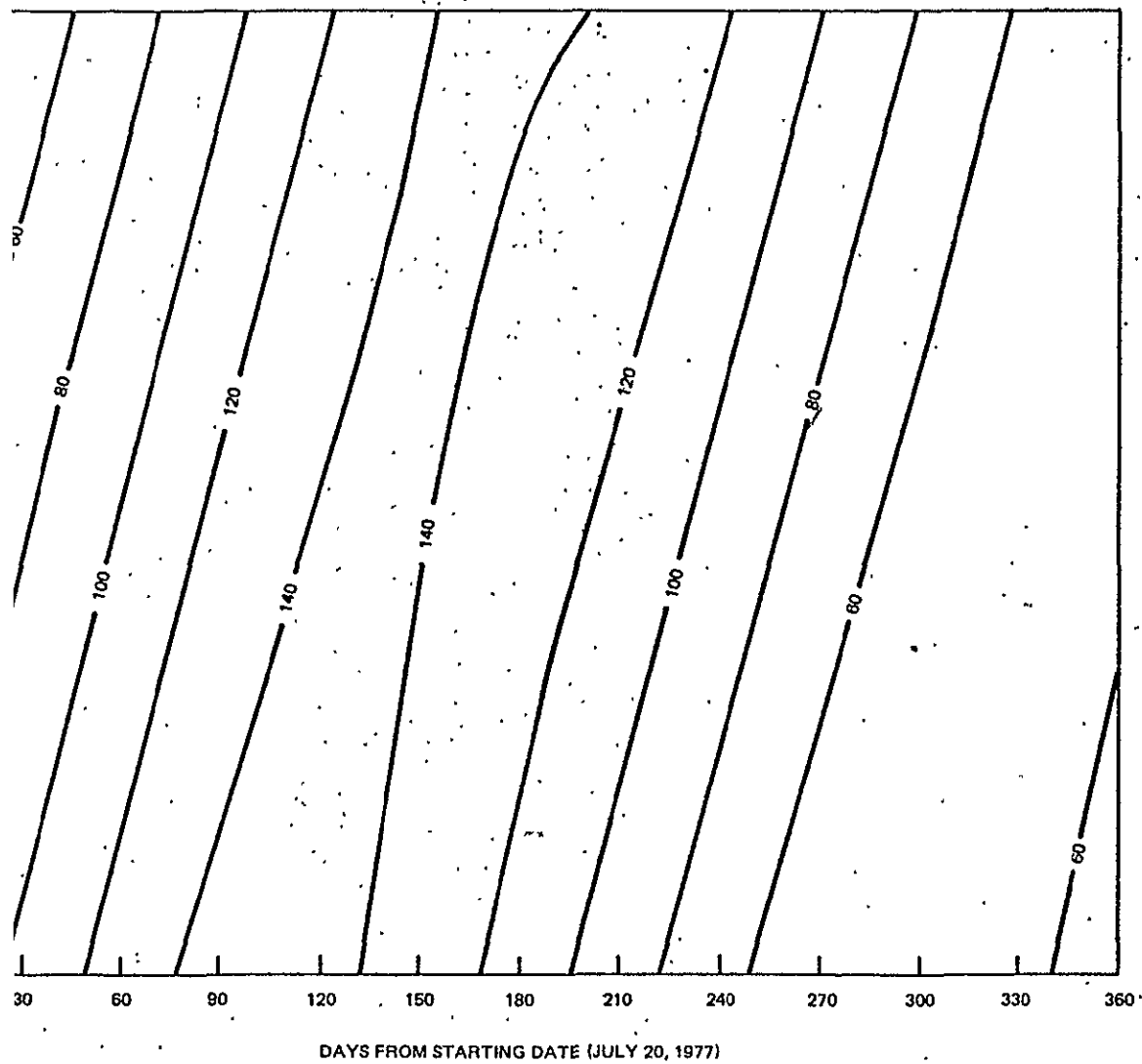


Figure D-4. Contours of Minimum Separation Angle During
3 Hours Prior to Apogee



i. Contours of Maximum Separation Angle During 3 Hours Prior to Apogee

APPENDIX E - EVOLUTION OF ORBITAL ELEMENTS

The Rapid Orbit Prediction (ROP) program was used to compute the orbital evolution, assuming that no stationkeeping maneuvers were performed during the mission. The gravitational potential included the fields due to the Earth, Moon, and Sun. A 6×6 field was assumed for the Earth. The figures are listed below:

1. Evolution of Semimajor Axis
2. Evolution of Eccentricity
3. Evolution of Inclination
4. Evolution of Node
5. Evolution of Argument of Perigee
6. Evolution of Groundtrack

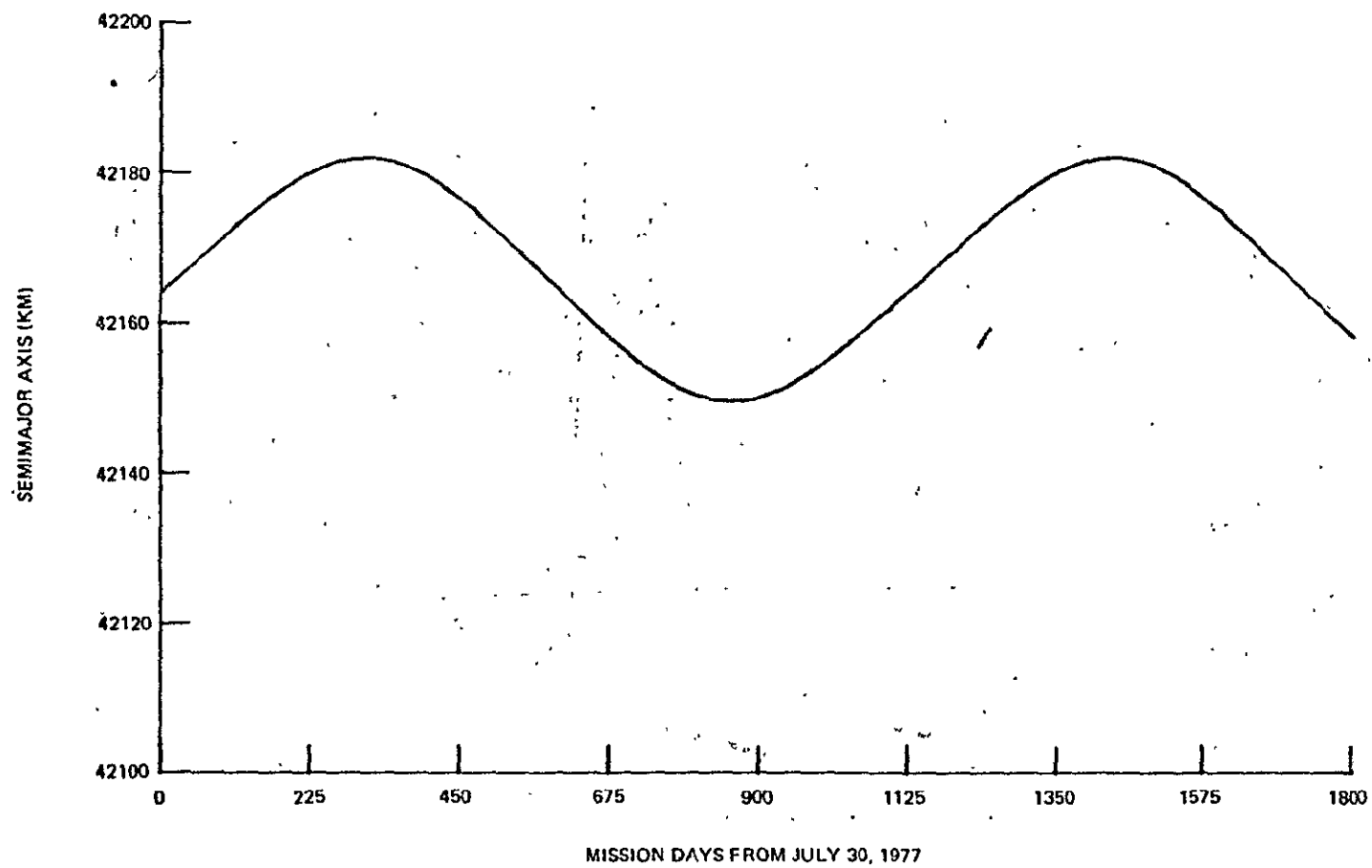


Figure E-1. Evolution of Semimajor Axis

E-3

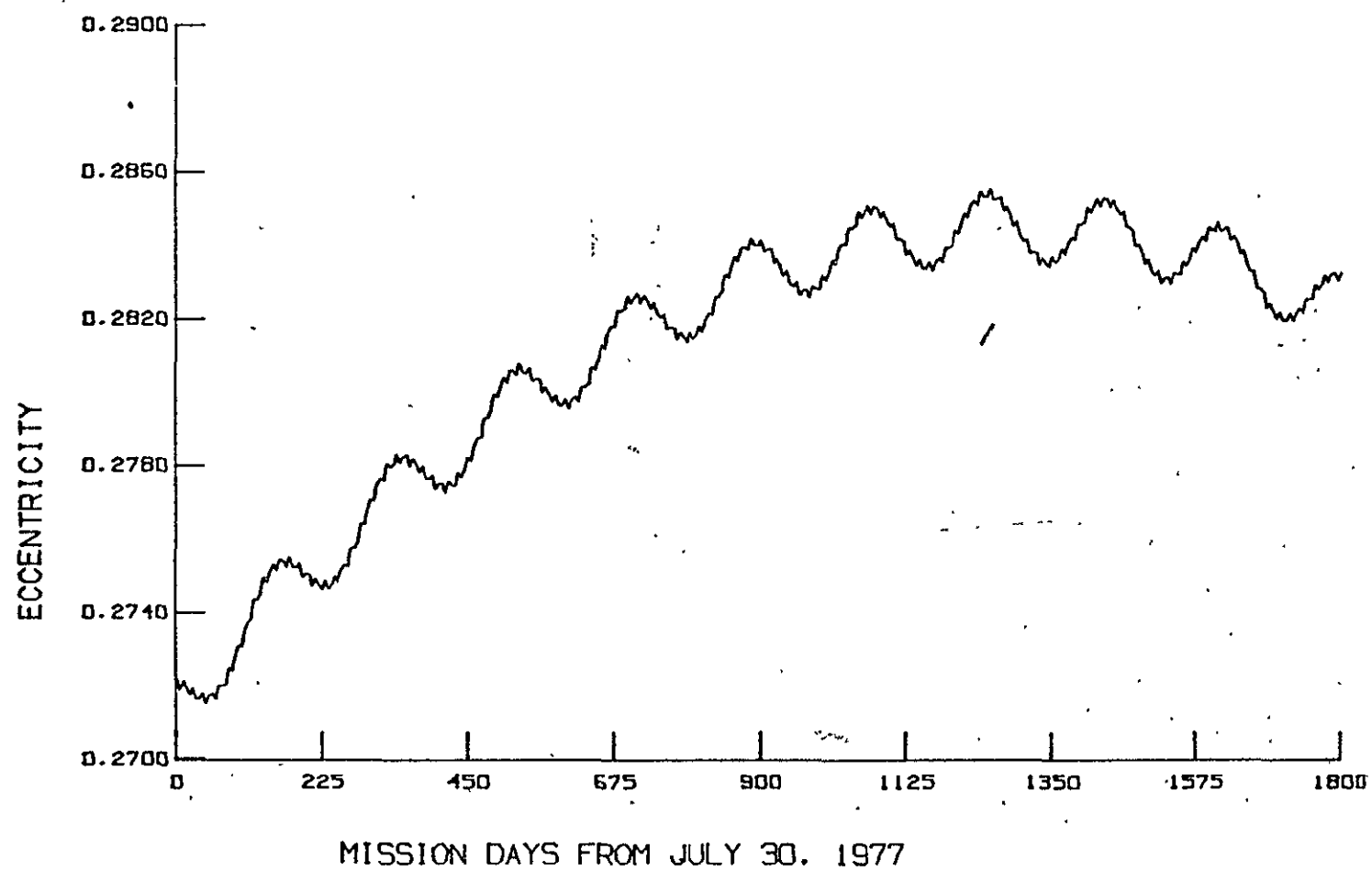


Figure E-2. Evolution of Eccentricity

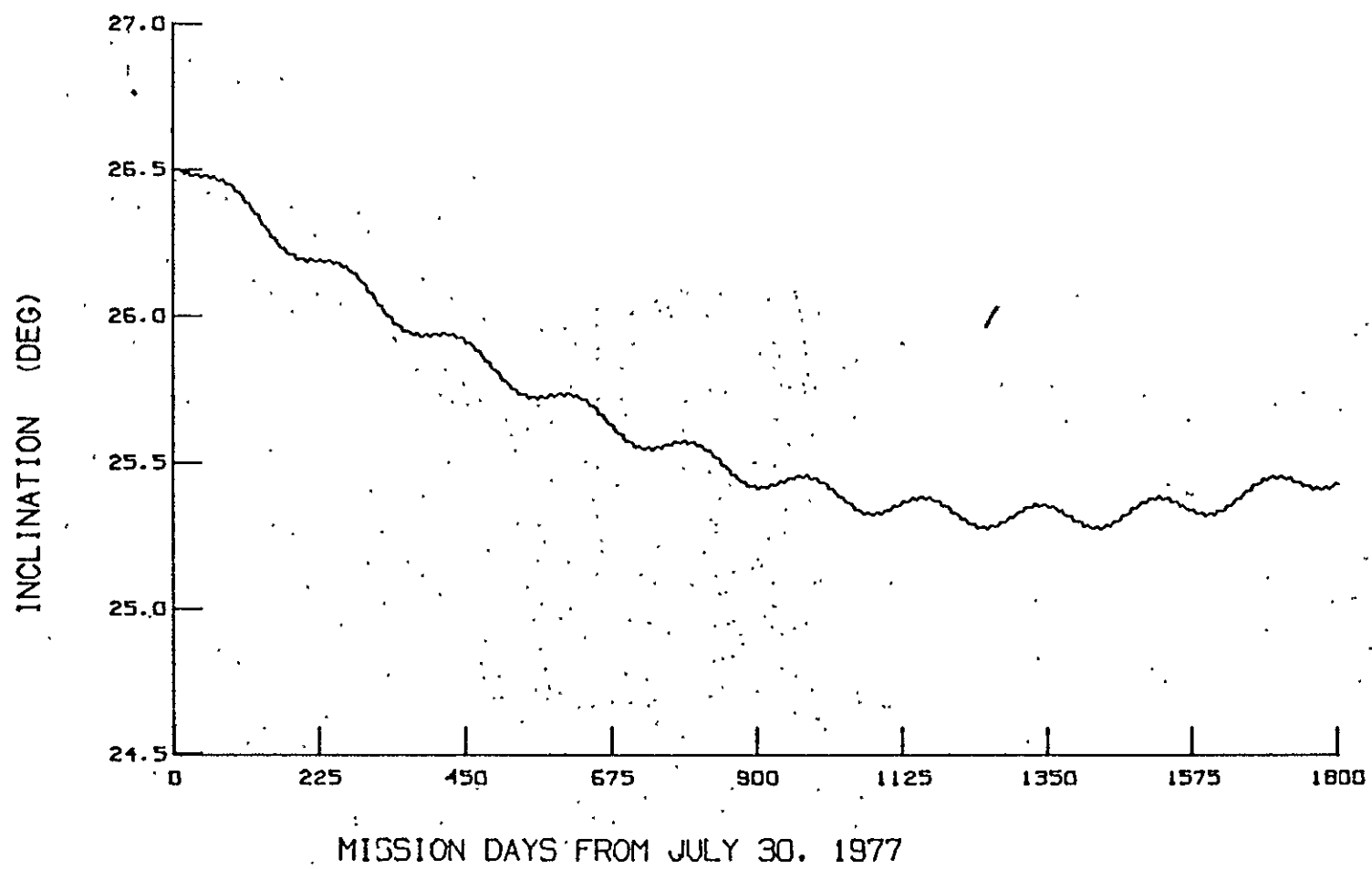


Figure E-3. Evolution of Inclination

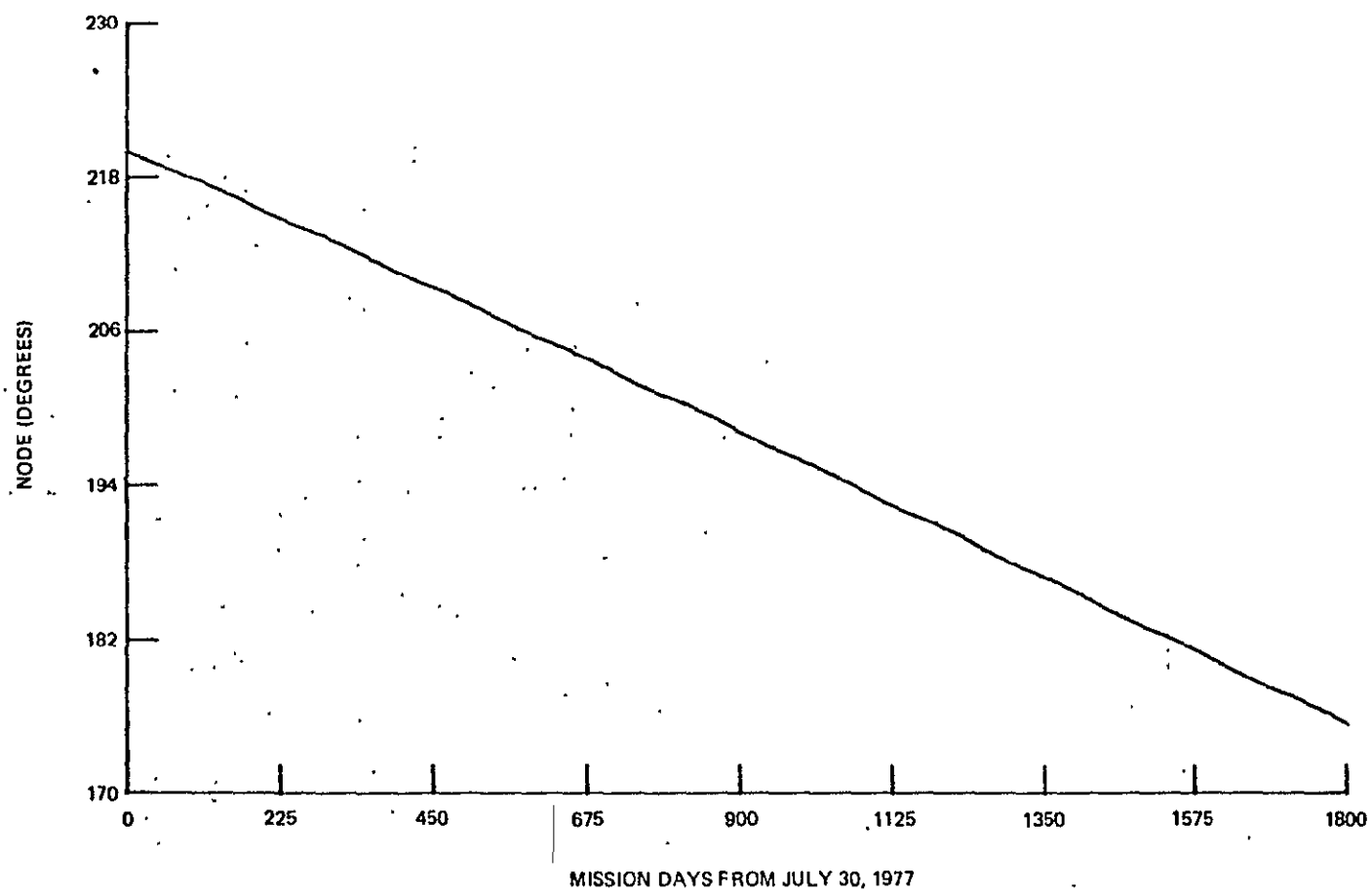


Figure E-4. Evolution of Node

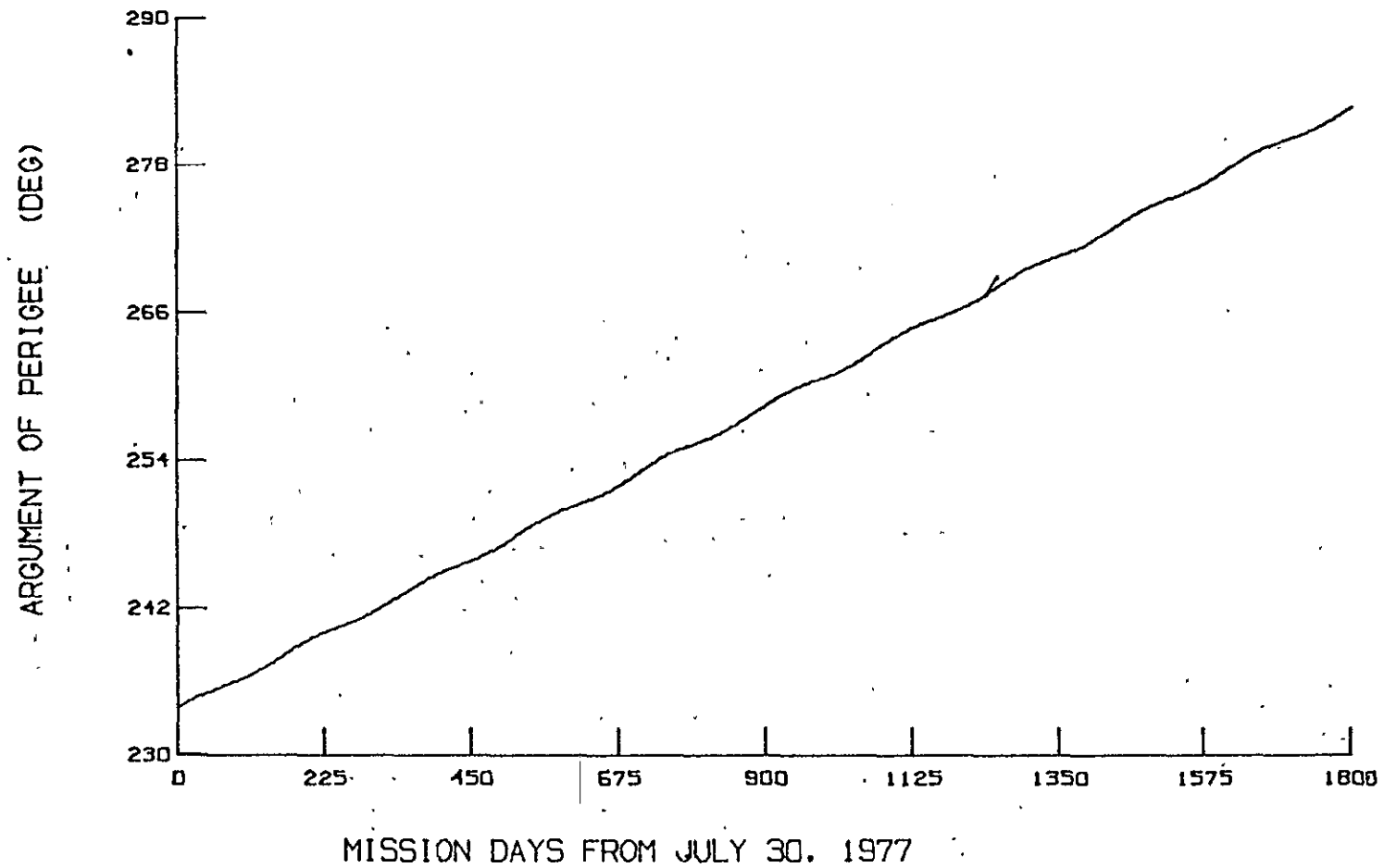


Figure E-5. Evolution of Argument of Perigee

E-7

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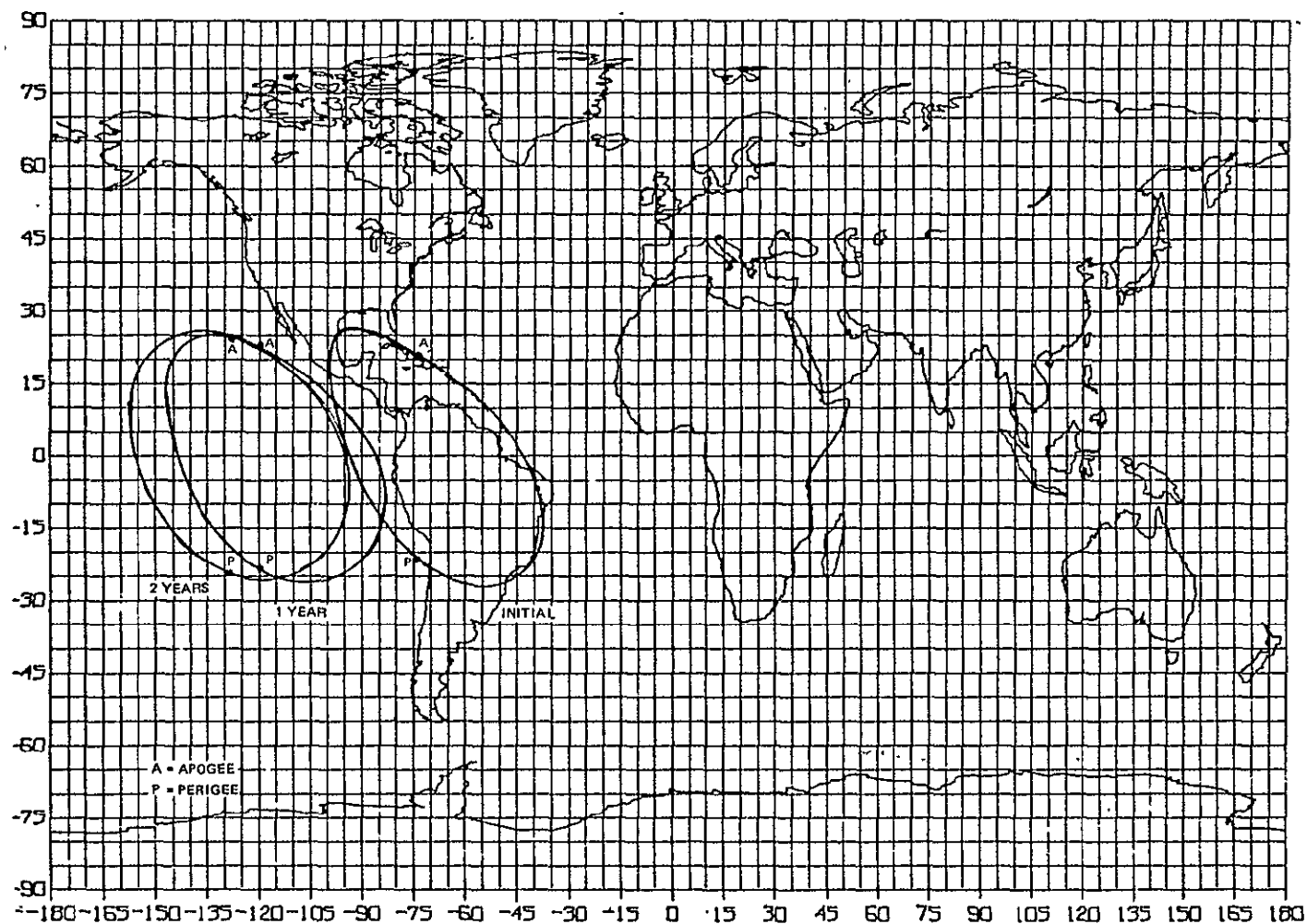


Figure E-6. Evolution of Groundtrack (1 of 2)

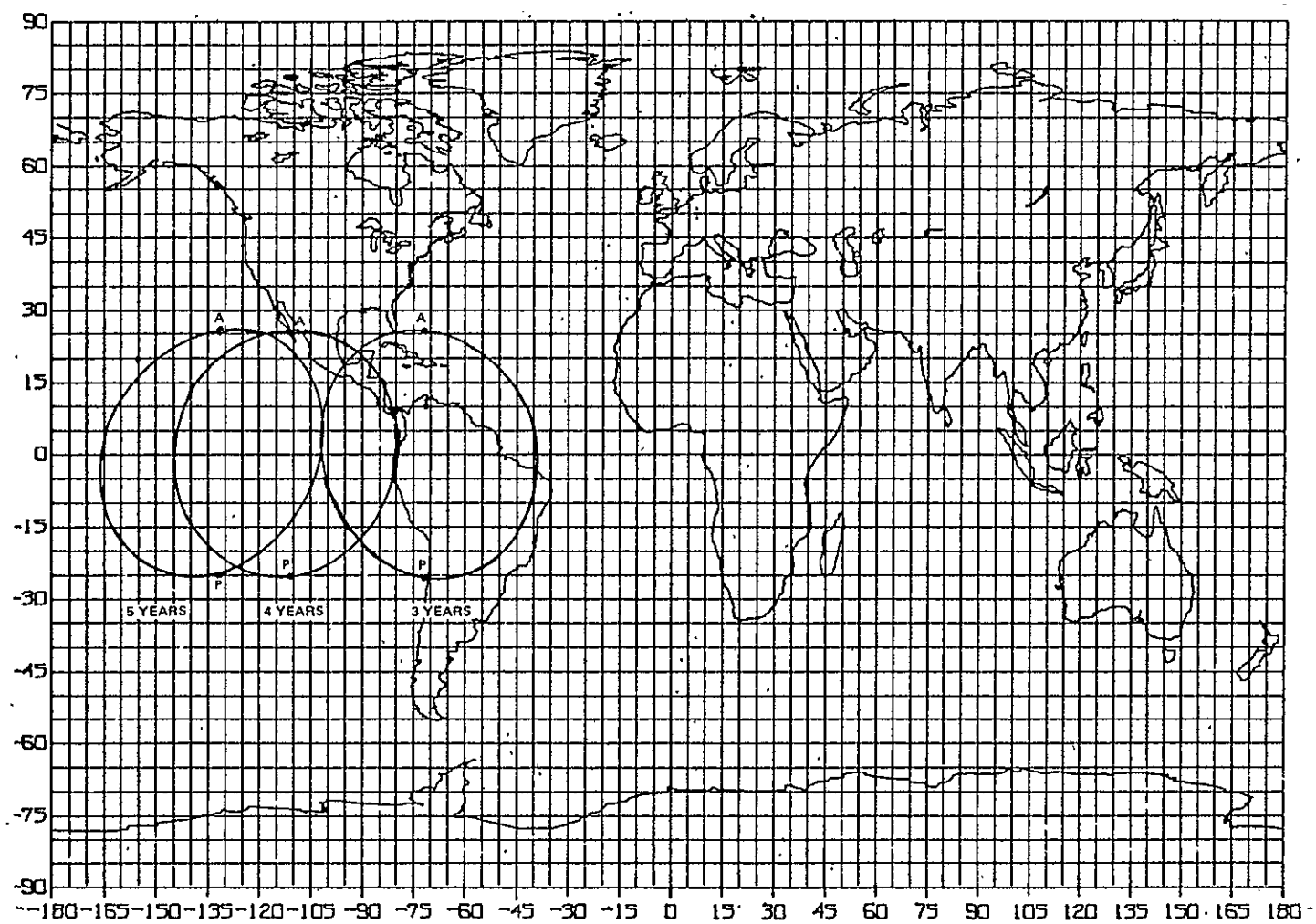


Figure E-6. Evolution of Groundtrack (2 of 2)